COAL

JAMES · TONGE

WESTMINSTER SERIES

Time allowed for reading is FOURTEEN DAYS. Fines for detention are ONE PENNY for the first week or part of week, and TWO PENCE for each succeeding week or part of week.

S

P4396 20m.1051 Form 27

The "Westminster" Series

COAL

COAL

BY

JAMES TONGE

LONDON
ARCHIBALD CONSTABLE & CO. LTD.
10 ORANGE STREET LEICESTER SQUARE W.C.
1907

BRADBURY, AGNEW, & CO. LD., PRINTERS,
LONDON AND TONBRIDGE.

C

PREFACE

It is now many years since a Work on Coal was presented to the public, and since that time knowledge of its natural history and appreciation of its manifold uses have been increased.

Coal is indispensable to all civilised nations; it is not surprising therefore that the origin, position and extent of the seams have exercised the best thought and enquiry of geologists and prospectors; that its discovery and working have stimulated the skill and demanded the best energies of engineers, and the heroism and labours of innumerable miners; that its economical utilisation and application have been obtained in spite of years of necessary labour and research on the part of learned men in many branches of science.

This book, though dealing only with the first and last of the aspects of the subject thus suggested, should be interesting and instructive not only to students of various sciences, but to the whole of those people who, though proud of the high commercial position of this country, are unaware as to how greatly this is due to our Coal supplies.

As a rule descriptions of mining practice have been avoided, though a few subjects here included are dealt with in the author's "Principles and Practice of Coal Mining," published by Messrs. Macmillan & Co., Ltd.

The latter book is intended particularly for students; the present work is of course written for a different public.

Some of the friends to whom I am indebted for advice and assistance and to whom thanks are now tendered are Mr. Bennett Brough, F.G.S., Mr. John Gerrard, H.M. Inspector of Mines, Mr. James Lomax, Petrologist, and Mr. Herbert Bolton, F.R.S.E.

JAMES TONGE.

WESTHOUGHTON,
October, 1907

CONTENTS

COAL.

CHAPTER I.

HISTORY.

Coal! What romance surrounds the word! Consider the strange natural history; the wonderful provision in an early geological age of the vast supplies for the future use of a higher type of animal than existed at the time; the skill and ingenuity of the engineer in finding the deeply-hidden beds and extracting them from their long resting place, and this in the face of such obstacles as water, fire, and noxious gas; the labour of thousands of men and boys in a subterranean world, and the toll of lives annually sacrificed therein; the innumerable purposes for which it is required, whereby human life on this earth may be made enjoyable, it might almost be said, possible.

In those remote ages of the early history of man, before the periods of metal began, there was little use for coal, so that, whether it was visible or not in the river beds or hill sides, man had probably not investigated its properties. But when the great discovery was made that certain substances could be melted by heat and moulded into various shapes and patterns the hill sides were robbed of the black

substance which could produce the fire necessary for smelting purposes.

And so, although pre-historic man had little use for this combustible, and obtained his supplies of fuel from the forests in or near which he lived, there were possibly some miners who smelted and worked the metals, and some smiths who made and tempered arms. It is easy therefore to imagine that fossil fuel was sometimes used for both these infant industries. However that may be, the Greeks and Romans were acquainted with this wonderful mineral. Two hundred and thirty-eight years before Christ, Theophrastus, the favourite pupil of Aristotle, in a treatise on "Stones," wrote of the nature, source and uses of coal. He says, "They call those fossil substances (λιθύς ἄνθρακας) Anthracite (or coal), and when broken up for use they are of an earthy character: nevertheless, they inflame and burn even like charcoal. These are found in Liguria and Elis, in the way to Olympias, over the mountains, and are used by the smiths."

From discoveries made by geologists and missionaries it has been clearly established that the Chinese, to whom so many great discoveries are attributed, were acquainted with fossil fuel from remote antiquity. It is probable that owing to their knowledge of the nature and properties of coal they were enabled to discover the method of, and to supply the means for, the manufacture of porcelain, gunpowder, paper, etc., and to engage in those useful arts so long practised by them. The collection of inflammable gas by the means at present employed in the distillation of coal is only an adaptation of the Chinese plan. The ancient Chinese methods of boring for coal are still adopted in certain parts

of the world, especially in the United States, Russia, etc., where the development of the oil industry requires rapid boring. The method consists in the employment of a rope with boring tool attached in place of the usual rigid iron rods. The rope was originally formed of bamboo fibres, the torsion of which was sufficient to rotate the tool after each blow; the tool itself consisted of a heavy cylinder of iron with cutters fixed at the lower end.

In England, unmistakable evidence of the working of coal by the Britons of a so-called pre-historic time can be supplied, and it is probable that some industries were practised before the invasion of this country by the Romans which have been considered impossible for the so-called barbarians who inhabited these islands at the time. That the Romans engaged in the mining of coal there is no doubt. Many of their stations were situated in close proximity to the outcrops of valuable seams; tools of a peculiarly Roman type have been found in old colliery workings; the plan or system of working has been discovered to be of a design associated with art as practised by the Romans; finally, coal and coal cinders have at several places been found in excavating Roman stations in various parts of England.

Trade in coal may be said to have started about 1215 A.D. At the time of the signing of the Magna Charta it was sold as an article of commerce, though previous to this time it had often been given to the monks as an offering, or in satisfaction of some claim upon the people held by the monastery. Britton, in his description of Peterborough Cathedral,[1] has the following paragraph taken from the

[1] "Cathedral Antiquities."

Saxon Chronicle of the Abbey of Peterborough:—"About this time (A.D. 852) the Abbot Ceolred let the land of Sempringham to Wulfred, who was to send each year to the monastery '60 loads of wood, 12 loads of coal, 6 loads of peat, 2 tuns full of fine ale, 2 neats carcases, 600 loaves, and 10 kilderkins of Welsh ale, 1 horse also each year, and 30 shillings and 1 night's entertainment.'"

In 1259 a charter was granted to the freemen of Newcastle by Henry III. to "dig for cole," and soon the ships were carrying fuel to London, where "sea-cole" was quickly utilised by the various manufacturers of the metropolis. In the reign of Edward I. (1272—1301) the smoke from burning coal caused such annoyance to the prelates, nobles and gentry of the city of London that they were unable to stay in the town—because of "the noisome smell and thick air caused by burning cole." A proclamation was therefore issued forbidding the use of coal. Its use, however, gradually became extended, and in the reign of Elizabeth it was largely used, though prejudice against it had not entirely disappeared. The Queen prohibited the burning of coal in London during the sitting of Parliament, as it was feared that "the health of the knights of the shires might suffer during their abode in the Metropolis."

From the 14th century there is a fairly clear historical account at least of the Newcastle coal-mining, and the working of coal in that century gradually spread to Durham and Yorkshire and finally to Lancashire, the Midlands and South Wales. In 1662, £200,000 per annum was raised by the "Hearth Tax," a tax imposed by Charles II. on every fireplace or hearth in England.

In the 17th century also English ships were already

carrying cargoes of coal to foreign ports, and though for a time the people in the chief towns of France, Belgium, Holland and Germany strongly objected to its use, the prejudice was in time overcome, and coal mines were soon being worked close to the walls of some of the chief towns.

But the 18th century is the most memorable in the history of coal. The invention of the steam engine by Watt in 1784 not only enabled coal to be worked more efficiently and safely from greater depths in spite of greater difficulties, but enabled new applications of steam to be devised, all of which required coal for the generation of the motive power. Moreover, railways, steamboats, mills and blast furnaces were soon introduced or increased in number. It is not remarkable that England should at once have advanced to the foremost position amongst the nations of the world, especially when it is remembered that she not only possesses, for a given area, the greatest number of rich seams of coal, but that large areas of the country contain valuable deposits of iron ore, many of which occur in close proximity to the seams of coal. It is this ample provision and fortunate combination of natural resources which has enabled England to produce larger quantities of machinery than any other country; to supply fuel, and the ships to carry it, for every other nation in the world; and to be the pioneer in most inventions, arts, manufactures and in science.

CHAPTER II.

OCCURRENCE.

Origin of Coal.—There is no more fascinating story than that of the origin of coal and the mode of its formation, whereby a happy provision was made which has proved to be of great advantage to the human race. Those great convulsions which altered the entire surface of the earth in its early history, coming as they did during the period of stratification and after various forms of animal and vegetable life had appeared, were the means of preserving vast quantities of vegetable matter, which, maturing during the countless ages that have elapsed since, have formed an inexhaustible store of valuable fuel.

The Period of Stratification, on account of its great influence in the formation of coal, is the most important epoch in the world's history. Previous to this time the earth was merely a rolling ball of more or less solid matter. Eventually a firmament surrounded it and water appeared; and this, aided by the sun, produced important results. The earth gradually solidified at the crust, shrinking, bending, cracking: water, fire and air all agencies in the work. The denudation of the strata by water and the carrying away and subsequent deposition of the particles by the same agent caused the first stratified deposits. The constant repetition of this process has at length resulted in many different deposits becoming filled in one above another, so

that the oldest are situated at the greatest depth, unless some later movement has altered the usual arrangement. These deposits are capable of classification according as they possess distinctive features either of texture, hardness, colour, thickness or fossils, and by these means may be identified by the geologist. There is no doubt that great movements occurred during the time of the formation of the stratified rocks, and there is evidence to show that nearly all exposed

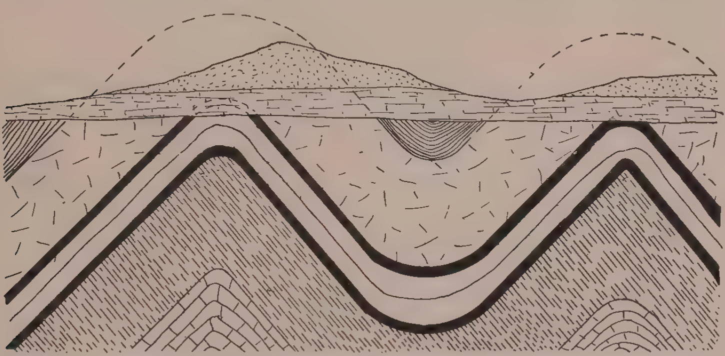


FIG. 1.—Effect of earth movements, denudation and subsequent deposition on strata forming the earth's crust.

land surfaces have been again and again submerged beneath the ocean, and that the various sea deposits have been again and again raised a great height above their present level. Igneous rocks have been pushed up in dykes and veins, amidst the stratified rocks. Consequently the original stratification has been frequently disturbed (Fig. 1), and the strata bent, folded or fractured (Fig. 2) in many ways. The relative ages of the various rock systems may be determined in different ways. When one stratum rests upon another, it is generally inferred that the lower bed was formed before the deposition of the upper began. Thus

when we observe how the strata rest upon one another in cliffs, railway cuttings, and mines, we can trace the order of succession. In addition to the composition and structure of the rocks, the greatest assistance in arriving at the identification of any particular formation is derived from fossils, that is to say, the impressions or casts of the remains of animals or vegetables, buried in the rocks. Each formation has its own particular fauna or flora.

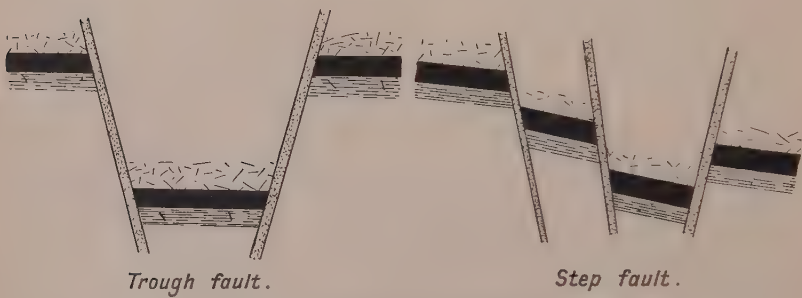


FIG. 2.—Faults or fractures in strata displacing seams of coal.

In all the stratified deposits, except the Laurentian, plants or animals of one type or another have been found. It is from the nature of these fossils that the stratified rocks have been divided into three great epochs or periods of time —Primary, Secondary, Tertiary. Corresponding to these great groups are three great life periods—Palaeozoic (Greek, palaios, ancient; zoe, life); Mesozoic (Greek, mesos, middle); and Cainozoic (Greek, kainos, recent). Each of the great groups is again divided into smaller groups, called Formations and Systems; a formation being a group of stratified rocks, the members of which have certain characteristics of age and composition in common.

Formation of Seams.—In carboniferous times, in spite of the great convulsions of the earth's crust referred to, there was a luxuriant vegetation covering great portions of the earth's surface, a vegetation more prolific than had ever been possible in the history of the earth previous to that time, or has been possible since. The conditions of atmosphere, soil, heat and moisture were exceptionally favourable to a luxuriant growth. Great contortions of the surface had caused valleys in which water lay in vast areas forming marshy ground and prolific swamps.

A tropical heat no doubt existed over the whole earth. It is thought by some scientists that the earth was for a long period nearer to the sun than at present and therefore warmed with greater intensity, while other scientists consider that the atmosphere was charged to a greater extent than it is now with carbon dioxide, which fed the plants and served to retain the genial warmth of the sun. A more accurate knowledge of the botany of coal-measure plants, however, serves to show that the latter idea is not so likely as the first. The hot rays of the sun and the warmth of the earth itself were sufficient to cause a moist atmosphere, suitable for the growth of the plants, so that the land surface was like a huge summer-house with natural warmth, moisture and enriched soil, and a constant temperature.

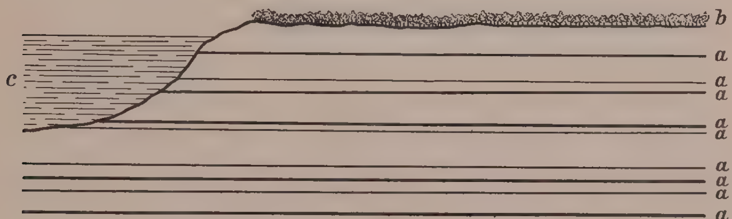
The coal-measure plants were no doubt originally derived from the sea, for it must be remembered that long before the carboniferous age the waters had covered the greater portion of the world's area. By the process of differentiation, that is to say, the change by which plants became specialised or modified, and took upon themselves the qualities or attributes of different species, the sea plants

developed powers enabling them to live on the land; in other words, all present species of plants have been derived from sea plants.

So through countless years of change the magnificent forests grew, stately trees and thick undergrowth alike flourishing, dying, falling to the ground and serving as fresh soil in which other vegetation might grow. Flowering trees were no doubt rare, but ferns, mosses, and other trees flourished abundantly. Animals of various kinds inhabited the forests; there were fishes in the rivers, reptiles basked on the edges of the swamps, and a few air-breathing animals—dragon-flies, scorpions, etc.—were to be found. Although the trilobite had disappeared, the fossils of many amphibians, such as frogs and salamanders, have been found. Somewhat similar processes, though on a limited scale, are even at this time taking place. An explorer, describing the dismal swamps of Virginia, says, "From the black water there rose a thick growth and upshooting of black stems of dead trees, mingled with the trunks and branches of others still living, and throwing out a most luxuriant vegetation. The trees were draped with long creepers and shrouds of Spanish moss, which fell from branch to branch, smothering the trees in their clammy embrace, or waving in pendulous folds in the air. Cypress, live oak, the logwood and pines struggled for life in the water, and about their stems floated blocks of timber on which lay tortoises and enormous frogs. Once a dark body of greater size plunged into a current which marked the course of a river; it was an alligator, many of which came into the swamps at times."

During the period of this rich growth, those early

catastrophes of the earth to which reference has been made were taking place, great convulsions, upheavals or lowerings, which caused the primeval forests to be overwhelmed and buried beneath the water and enormous accumulations of earthy *débris* and sediment. Alternate elevation and subsidence occurred, and after sand and shale had been deposited and the water had been again driven back, conditions suitable for plant growth again prevailed. When



a, a, a. Seams of Coal.
b. Growing Forest.
c. Sea.
Owing to alternate elevation and depression of land surface or sea level, vegetation first flourishes and afterwards is submerged and interlying strata deposited.

FIG. 3.

numerous coal seams therefore are found one above another (Fig. 3) it is evident that the process must have been repeated time after time, each coal seam representing the period when the water was driven back and vegetation enabled to flourish, and the intermediate strata, periods during which the decaying vegetable matter was submerged, and gradually covered by accumulations of sand and mud. In this way nature's storehouse of fuel was filled, and a record of the manner in which it was done has been supplied in the fossils of the remains of land animals and plants (see p. 21) in the

roof and floor of seams of coal and of marine fauna and flora in the intermediate strata. It is true that considerable doubt exists as to the original places of growth of the vegetable matter composing the great coal deposits, whether the forests grew on the sites which the beds of coal now occupy, springing up and thriving on the borders of great lakes, into which they have ultimately fallen, or whether the accumulations have floated for a long time and from great distances before sinking near the mouths of rivers on delta deposits. This question will be discussed later.

> "Yes! countless years of change have passed since then!
> Change to the earth's fair surface, change to men;
> Woods, hills, plains, islands, seas, are swept away;
> Unnumbered states have crumbled to decay:
> While 'neath the soil, a thousand fathoms deep,
> The fallen monarchs of the forest sleep."[1]

It is true that coal in the mass exhibits externally very little appearance of organic matter, but when examined microscopically its vegetable structure may be observed, and ferns or branches may be found impressed as fossils on the roof of the seam, or the roots of some of the trees may be discovered in the underclay. But the proof of the vegetable origin of coal does not depend merely on the microscopical evidence of its structure. Chemical analysis shows it to be composed of the same elements as wood—carbon, hydrogen, oxygen, and nitrogen—though in varying proportions, according to the changes it has undergone in the period of its deposition and decomposition.

The processes by which this vegetable matter has been transformed into coal as it is found to-day and the cause

[1] Oxford University Prize Poem, "Coal," by T. L. Thomas, 1863.

of the many different qualities are questions of great importance.

It is clear that the thickness of coal seams is accounted for by the abundance of the vegetation or the length of the period during which growth was uninterrupted. But this does not account for the formation of various grades of coal in separate seams or in various localities. The fuels which have experienced least alteration from their original vegetable state are peat and lignites (see p. 132), and these contain smaller percentages of carbon than the more valuable classes of coals, namely, the bituminous, semi-bituminous, and anthracites.

It is well known that certain agents have been at work in the transformation of vegetable matter into coal, the chief of which are the heat of the earth and the heat generated in the decomposition of the organic matter, the pressure of the superincumbent or overlying strata, the effect of dislocations or distortions of the earth's crust owing to earth movements or volcanic eruptions, and finally the great length of time during which any or all of these agents have operated. It is, however, doubtful which of these have acted as causes of the transformation or which have merely modified the conditions, and in this way affected the change by merely increasing or retarding the rate at which the process has gone on. It is difficult to fix definitely the part played by each of these agents, viz., pressure, heat, time, and movements of the crust.

As a rule those coals which are found in formations more recent than the carboniferous are inferior to the coals of the true coal measures, *i.e.*, the upper carboniferous rocks. It is sometimes contended that this is due to the fact

that less pressure has been imposed upon the vegetable deposits and less time has been available for the process. On the other hand, many seams of coal of poor quality are found in the carboniferous system. They do not appear to have passed through as complete a process of metamorphism or change as the seams that are of better quality.

It is clear, therefore, that time and pressure alone do not account for the degree of change in coal. The most important cause is heat; the other agents, while essential to the completion of the transformation, affect the metamorphism by merely accelerating or retarding the process.[1]

Coal, therefore, is the result of the distillation of the original vegetable matter caused by the natural heat of the earth and the heat generated in decomposition, and its ultimate composition is dependent upon the amount of hydrocarbon and other gases which have been able to escape from the decomposing mass. Any agent, therefore, which has assisted in or retarded the escape of the gases has been the means of influencing the composition and character of the product coal. Heat, whether of low or high intensity, and whether applied for a short time or continued throughout long periods, affects the distillation of the coal, and as sufficient heat to do this can be accounted for either in the internal heat of the earth or the influence of volcanic action, no other explanation is possible or necessary. The seams of coal which have suffered the greatest metamorphism are those overlain by porous rocks which have allowed the gases to escape, and as it is clear that rocks of comparatively recent formation may have been quite as porous as more ancient rocks, it is clear that they would affect the nature

[1] See "Economic Geology," by R. Campbell.

of the seam in the way described and thus enable more complete distillation in spite of less time and pressure being available. Where a seam has been covered with impermeable rocks, and buried under vast accumulations, the change in its composition will, it is true, be all the greater on account of the increased time during which the causes have operated, and similarly seams will be affected by volcanic eruptions or earth movements which occur during the period of their distillation, but these agents, unless they produce heat, merely contribute to, and do not cause, the change.

CHAPTER III.

MODE OF FORMATION OF COAL SEAMS.

The "In situ" and "Drift" Theories of Deposition. —It is now necessary to enquire more carefully into the method by which the great supplies of vegetable matter arrived at their present position. At the present moment there are accumulations of drift wood taking place on some of the large rivers of Africa and America, and though it is unlikely that these are destined to become seams of coal, they assist in arriving at a conclusion in regard to the deposition of coal seams.

Captain Hall, who explored the great river Atchafalaya, a tributary of the Mississippi, wrote in regard to its enormous raftage: "The river just mentioned flows out of the Mississippi at a point about 250 miles from the sea. Twenty-seven miles from the efflux the raft begins, and extends over a space of 20 miles; but as the whole distance is not filled up with timber, the aggregate raft is only 10 miles long. The width of the Atchafalaya is 220 yards. The raft extends from bank to bank, and is supposed to be about 8 feet thick. It has been accumulating for more than fifty years, and is made annually larger by supplies of trees drifted into the river from the Mississippi."

It is easy to imagine that in process of time this great mass of wood will become covered up by sand and mud, and above it a soil may be formed, rich with vegetation (as

indeed occurs even now at certain seasons, the whole surface of the drift wood being covered with grasses and flowering plants), and finally a stratum of peat or lignite may be formed. In this way some coal areas comprised of seams one above another, the result of vegetation which grew at a considerable distance from the present point of the seams, were no doubt laid down. This is known as the "drift" method. On the other hand such a theory of the formation is not consistent with the character of many other coal basins, the vegetation of which they are formed having evidently grown on sites now occupied by the seams. This is known as the "*in situ*" method. Or it is possible that the vegetation sprang up and flourished on the borders of vast lakes, into which they were finally swept by one of the agencies referred to. This is spoken of as the "lacustrine or fluviatile" theory. If the various coal basins and the seams occurring therein are carefully studied, evidence in support of one of these three processes can almost certainly be found.

THE "IN SITU" METHOD OF DEPOSITION.—It is easy to understand the mode of formation of the coal seams by this method, which has already been described (p. 11), and it is only necessary to add that according to this theory the recurring periods, first of prolific vegetation, then of submergence, left the beds of fuel with the deposits of sand and mud upon them practically in the same position as at first. Many important reasons can be given in favour of this theory. The seams, which spread over large areas, are generally uniform in thickness, and the strata above and below the seam are also similar over large areas. Trunks of trees have been found erect, with the upper portion in

the roof and the bottom part in the underclay, the roots and rootlets being found quite complete and evidently exactly as they grew. The small roots of smaller plants are often found in the underclay corresponding to the lepidodendron, calamites and ferns found in the coal just above. Up to the present time no coal beds have been found which are entirely free from rootlets. If the vegetation was drifted, it is reasonable to suppose that in a few cases the mass might drift on to rocks which contained no vegetable remains of any kind. Again, it is not easy to suppose that rivers could carry great masses of vegetation for enormous distances, and at length deposit their floating burdens so evenly; or to suppose that this process kept recurring, thus forming separate seams.

On the other hand, the strata above and below the seam contain many fossils of sea plants and animals, and this is good evidence that the sea was the agent of the deposition of the rocks; and it may also be urged that if coal seams are the result of drift and sedimentation it would be natural to expect a large amount of ash and *débris* to have been deposited in the vegetation, and even fish and other remains might be looked for for the same reason. Finally, it is found that the beds of fireclay on which the coal seams lie are invariably free from lime and alkalies, these minerals having been absorbed by the roots of growing plants.

It is evident, therefore, that if the whole of these arguments in favour of the "*in situ*" theory could without exception be sustained, the whole would form practically conclusive proof that the vegetation grew on the present site of the seams. This is not possible, however, and there

are many strong proofs that some seams, at any rate, have not thus been laid down.

THE "DRIFT" METHOD OF DEPOSITION.—The theory of the formation of coal seams by drift is supported by many geologists, who contend that the huge masses of decayed vegetable matter, after lying in vast swamps for a considerable time, were carried out by streams of water into lakes or estuaries. When the water became motionless, it is supposed that the vegetation floated upon the surface, spreading out more or less uniformly over great areas, until finally it sank to the bottom. After this the lake became filled with *débris* washed down by the rivers, the lighter sand and mud being carried farthest by the current, until this also sank, covering up the vegetable matter and forming the strata now found above the seam. In support of this theory, it is pointed out that many beds of fireclay are found without any sign of coal above them, and it is natural to ask if fireclay is the result of the absorption of the lime and alkalies of the soil by the roots of the growing plants, what has become of the plants which grew upon those beds, and have now no seams of coal above them? There are also many seams of coal having no bed of fireclay beneath; seams have even been found deposited upon a distinctly strange formation. It is evident, therefore, that if the fireclay was necessary for the plants' growth, the latter must have flourished upon some other soil than that upon which they are now found. Even when the underclays are found they do not always resemble soils, being quite homogenous, parallel to the strata below, but not always to the coal above. Again, in the seams themselves there are thin partings of shale or clod, but, however thin

these are, the roots of plants of the seam above have not disturbed or penetrated them. Some of these partings thin out in one direction and disappear altogether, while in the opposite direction their thickness increases until one seam becomes two with many yards of strata between. This variation in the thickness of the measures is quite consistent with the theory that the *débris* has been carried down into lake areas, deposition taking place according to the specific gravity of the particles. These partings are often persistent over large areas, and it is probable that if the coal seams were laid down "*in situ*" the river beds and variations in the quantity of vegetation would have interrupted its continuity. Finally, most geologists agree that "Cannel" coal is of marine origin. Large quantities of fish remains are found in it, and its general structure agrees with the "drift" idea. There is difficulty in denying the marine origin of "Cannel" coal, containing as it does such an abundance of fish remains, shells, and minute crustacea, besides a great quantity of mineral ash. But in these respects it is unlike all other coals, and as seams of Cannel are found to be variable in thickness and limited in extent, they may have been formed either by drift or deposit.

Taking all the above points into consideration, it is evident that it is both unwise and unnecessary to assume a definite mode of formation for all coal seams. Many beds of coal are probably the result of one method of deposition of vegetable matter, while the vegetation forming other seams has been subjected to quite different processes.

CHAPTER IV.

FOSSILS OF THE COAL MEASURES.

Fossils have been described by a well-known geologist, Bergmann, as "medals of creation," and this aptly illus-

Photo.] [*J. Lomax.*

Fig. 4.—Portion of a large nodule from the roof (matrix cut away) composed of Gastrioceras Carbonarium Listerii, etc. ($\frac{1}{3}$ natural size).

trates their nature and use. They are the changed remains or impressions of natural objects which existed in their true state in early or recent geological times. In some cases they are merely the casts or impressions of the outer surfaces of the remains of plants or animals, formed by the matrix in which they lie. In other cases the original

organic body has disappeared, and subsequently infiltration has filled the mould with mineral matter, often some of the surrounding rock, and formed a cast which is destitute of internal structure, but yet shows the outer form of the original body. More rarely a fossil may be an actual petrifaction in which the organic object has become mineralised and so preserved, whilst it retains its original structure more or less perfectly.

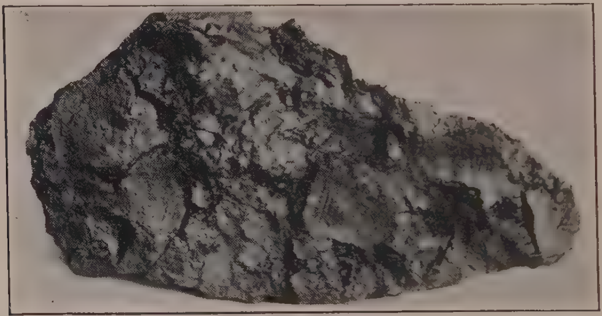


Photo.] [*J. Lomax.*

FIG. 5.—Shale composed of marine shells Aviculopecten Papyaceus (½ natural size).

In one of these ways the beautiful and often perfect impressions or remains of branches, leaves, roots, animals, etc., found in or adjacent to beds of coal, have been formed.

The shales associated with coal seams are usually fairly fossiliferous, yielding at times an abundance of plant remains, or more rarely various forms of animal life. It is not often that the same shale bed yields both. For some reason the shales immediately overlying coal seams (roof shales) are the most prolific both of animal and

plant remains. Clay ironstone, either in the form of thin bands or rows of nodules, occurs frequently in the shales, and often contains remains in a far better condition of preservation than those in the surrounding shales. Some of the ironstone bands are so heavily charged with the shells of Anthracosia (Carbonicola) that they have received the name of "mussel-bands."

The sandstones of the coal measures are less fossiliferous than the shales, any remains found in them being in the form of internal and external casts, the original organic body having wholly disappeared.

Notwithstanding this, fine examples of the casts of stems of the larger coal plants, such as Lepidodendron and Sigillaria of large size with the leaf scars well preserved are frequently found. Similarly, the huge spreading roots of the Stigmaria also occur in good condition in the sandstones, and give unmistakable evidence of the enormous size to which many of the coal plants attained. While it is almost certain that in those cases where we find a coal seam lying upon a bed of underclay or warrant earth, the latter permeated in all directions with rootlets, that we are dealing with an old land surface (see p. 11), and that the coal actually grew where we now find it, it is nevertheless equally certain that the shales which are repositories of both animal and plant remains were formed in lagoons or swamps often open to rivers, or the brackish waters of estuaries.

The remains of coal plants which are found in shales were therefore water-borne, whilst the animal remains in all probability were capable of living in the lagoon waters, notwithstanding the fact that these waters received vast

deposits of mud, and were almost always more or less brackish.

The practical value of fossils in the determination of definite horizons or levels in the rocks is now known to be very great, and a knowledge of the commonest forms is at least essential to every miner. Certain fossils, as for example, *Tellinomya robusta*, are only known to occur at a single horizon: in this case, in the roof of the Wigan Cannel seam, and therefore the finding of this species would furnish strong presumptive evidence that the Cannel seam was not far off. More often a series of fossils of different species are known to occur together in rocks which may be between two coal seams, or even at a considerable distance above or below them. The finding of the bulk of these species in similar association when opening new ground would naturally cause a comparison to be made between the rocks at this level and those which occurred above and below the known horizon of the fossils, with a strong probability that the two would be found to agree within narrow limits. If this proved to be the case further boring or exploratory work could be carried on with greater confidence, and with a definite end in view, *i.e.*, the finding of seams similar in character to those occurring below the horizon level of the suite of fossils in the known district. Certain fossils are entirely restricted to one or more levels, so far as is known, and whilst it is always within the bounds of probability that their range may be extended by further research, their occurrence can be regarded as indicating one or other of these levels, and other confirmatory clues looked for. In practice this is found not at all difficult, as each horizon or level possesses

its own special characters of shale, grit, or some other feature which, added to the presence of the fossils, makes the determination reasonably sure. The special branch of science which concerns itself with the study and elucidation of fossils is called Palæontology. The character of the fossils which occur in the English coalfields is very nearly the same for all. Those of the Lancashire and Staffordshire coalfields are the best known and most numerous.

Fauna.

Animal life during the coal-measure period was probably much more abundant than is usually supposed, although it did not compare in numbers or species with the more purely marine phase which preceded it, viz., the carboniferous limestone.

Hugh Miller, in picturing the animals in the carboniferous forests, says, "There is silence all round, uninterrupted save by the sudden splash of some reptile fish that has risen to the surface in pursuit of its prey, or when a sudden breeze stirs the hot air and shakes the fronds of the giant ferns or the catkins of the reeds. The wide continent before us is a continent devoid of animal life, save that its pools and rivers abound in fish and mollusca, and that millions and tens of millions of the infusory tribe swarm in the bogs and marshes. Here and there, too, an insect of strange form flutters among the leaves." This poetic and eloquent description is hardly correct in view of the later discoveries of many forms of air-breathing animals. The remains of nearly thirty species of land-dwelling or amphibious reptiles have been brought to light, and these

must have lived on the borders of estuaries or in the marshes and muddy waters of their shores.

Amphibia.—The highest class at present known to have existed is that of the Amphibia. Most of the members of the class, with the exception of *Anthracosaurus* and *Loxomma* were comparatively small, possessing feeble limbs hardly sufficient to support the whole weight of the elongated body. A long tail was present, whilst the head was usually flattened and triangular in form. Teeth were present, the dentine of which was much infolded, giving a characteristic labyrinthine aspect on a cross section. All belonged to the *Stegocephalian* or *Labyrinthodont* order, and no less than a score of genera are known from British coal measures alone, the greater number having been found in the anthracite coals of the Castlecomer coalfield of Ireland. The large forms probably grew to a length of six feet or more. Remains doubtfully referred to as the larger labyrinthodonta have been found in the middle coal measures of Lancashire, whilst the lower measures in the neighbourhood of Colne have yielded a small form (*Hylonomus Wildii*), a genus represented also in the Nova Scotia coalfield.

Pisces.—The lagoons and waterways of the coal-measure swamps were tenanted by a numerous series of fishes, many of large size and predatory character, whilst others were comparatively small. Shark-like forms are represented mainly by fin spines and teeth, amongst the chief being the large denticulate spines of various species of *Pleuracanthus*, and the curious tri-cuspid teeth known as *Diplodus:* crushing teeth like those of *Pleuroplax* and *Helodus*, and teeth with a crenulated cutting edge like those of *Ctenoptychius* and *Callopristodus*. The middle coal measures

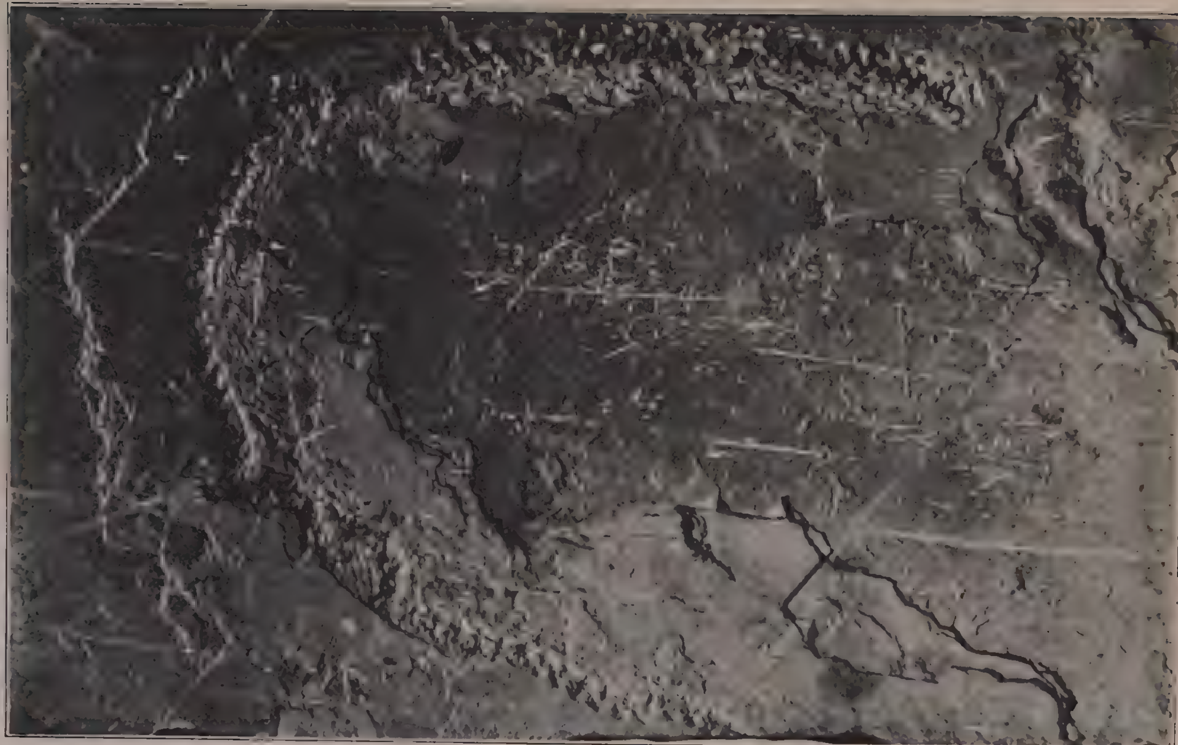


FIG. 6.—An eel-like Amphibian from the floor beneath the Anthracite coal, Jarrow Colliery, Queen's County, Ireland.

also frequently yield the stout dorsal fin spines of *Sphenacanthus*, which bear an ornamentation of parallel longitudinal ridges. The name *Gyracanthus* has been given to certain asymmetrical spines having a somewhat rounded anterior border and ornamented with oblique ridges. They are supposed to have been borne in pairs on the front edge of the pectoral fins. The teeth of *Ctenodus* are somewhat similar to those of the living *Ceratodus* in appearance, being triangular plates of bone, the upper surface of which is raised into parallel or diverging ridges with a crenulated or toothed edge.

Megalichthys hibbertii. This species is usually represented by large thick rhomboidal scales heavily coated with a layer of dense black ganoine and finely punctated. The teeth are conical, rounded in section and bear an ornament of fine vertical lines.

Strepsodus sauroides. Represented usually by large semi-rounded scales, ornamented with backwardly directed ridges, and by large laniary teeth which are flattened antero-posteriorly and doubly curved near the apex. The inner surface is ornamented by fine parallel raised lines. The remaining portions of the teeth are smooth, and acutely conical. The teeth of the lower jaw are much larger than those of the upper.

Rhizodopsis sauroides. This is one of the commonest coal-measure fishes, and grew to a length of about eighteen inches. Lower jaws, filled with a close series of small acutely pointed teeth, with larger laniary teeth at wide intervals, are by no means uncommon. The scales are somewhat pear-shaped and marked by a double series of concentric and radial lines.

Coelacanthus. The representatives of this genus are small slender bodied fishes, sometimes found almost whole. The head is comparatively large, the opercular apparatus especially so. The cranial bones have a partially tuberculated layer of ganoine. Prof. Huxley has described the scales of *C. elegans* as "thin, flat and cycloidal, the middle of the hind border being prolonged backwards." The exposed portion of each scale is nearly triangular. The scale ornament consists of ridges converging towards a central line. *Rhadinichthys.* Several species of this genus are known. *R. Wardii*, occurring in the Staffordshire and Lancashire coalfields. It rarely exceeds four inches in length. The scales bear parallel rows of fine tuberculations passing obliquely backwards and downwards to the posterior margin which is serrated.

Elonichthys semistriatus. Usually represented by small scales, ornamented with simple or forked striations passing obliquely backwards and downwards and terminating in an irregular network, or in a few scattered pits. The teeth are smooth, slender and incurved. Other species are *E. semistriatus*, *E. Aitkeni* and *E. Egertoni.*

Cheirodus granulosus. Deep bodied fishes of rhomboidal form. The body slopes sharply upwards from the hinder part of the head to an acute angle about the middle of the back from which it descends rapidly to the tail. The ventral angle is nearer the tail than that of the back and is also more acute. The scales are ornamented with coarse granules or tuberculations in fairly regular lines.

Platysomus parvulus. A deep-bodied fish of small size, with a comparatively large head, the bones of which are partly striated and partly granulated. The body scales are

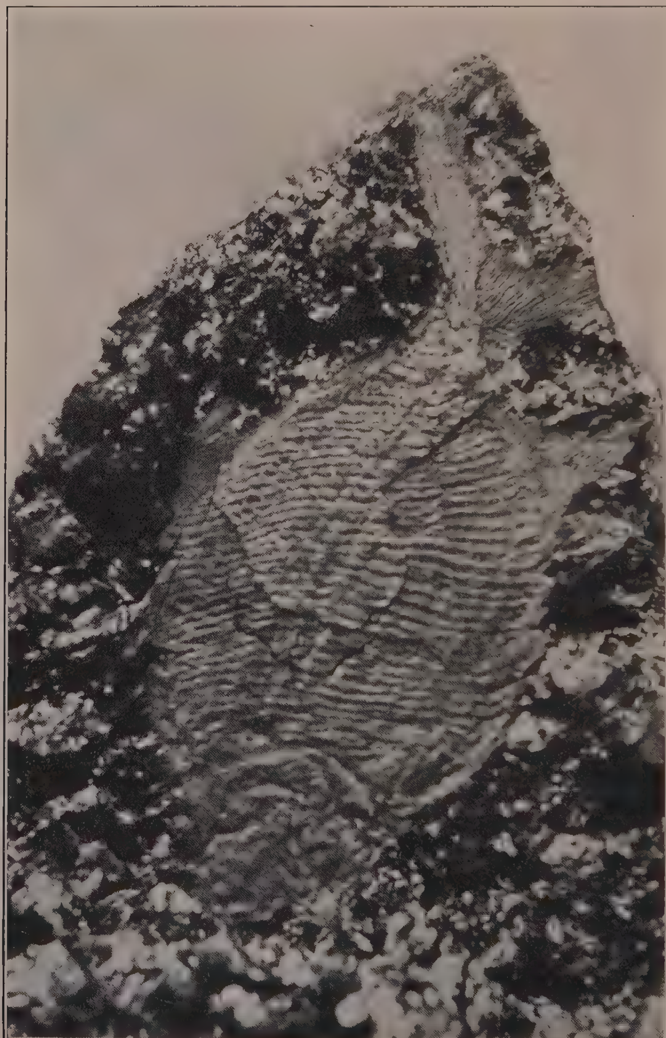


FIG. 7.—Mesolepis Scalaries (Young).

greater in depth than length, with an ornament of vertical disposed striæ. Upon the scales of the dorsal, ventral and anal regions, the striæ are oblique.

Acanthodes Wardii. Chiefly known by broad flattened fin spines having a single groove and faint ridge nearly parallel to the anterior border. The scales are small and smooth.

INSECTA.—-Insect remains have not hitherto proved abundant in British coal measures, but the Commentry coalfield of Central France and the Saarbrucken of Germany have yielded a great number, both of genera and species. Of these, examples of *Neuroptera, i.e.*, insects which have generally four wings marked with a network of many nerves, are most numerous, being twice as abundant as examples of *Orthoptera, i.e.*, insects with wing covers that overlap at the top when shut, under which are the true wings, which fold lengthwise like a fan. A striking feature of these forms was their huge size, some species having a spread of wing of nearly two feet. From the Derbyshire coalfield has been obtained an example of the Orthoptera, *Archæopilus*, having a spread of wing of fourteen inches, and still more recently neuropterous and orthopterous remains, and an example of *Etoblattina* have been found in shales over the Arley mine at Rochdale.

MYRIOPODA.—Quite fifty species of Myriopoda are known, many occurring in the English coalfields. Of these, the most common are :—

Euphoberia, in which the many segments of the body all possessed two pairs of legs, and *Xylobius*, in which the dorsal plates are more or less united.

Arachnida.—Fossil spiders and scorpions have been recorded from several coalfields: *Architarbus soboralis*, from Padiham, Lancashire; *Eorphrynus Prestwichii*, from Coalbrookdale; and *Eoscorpius Sparthensis*, from the middle coal measures of Rochdale.

Xiphosura.—Forms closely allied to the King crab have been found in most of the coalfields. *Prestwichia rotundata* is fairly widely distributed. It is a broad squat form having seven abdominal segments, and short cephalic and caudal spines. Other forms are *P. birtwelli*, *Cyclus Johnsoni* and *C. Scottii*, known only from the cephalothorax and *Bellinurus bellulus*, olim *Limulus limuloides.*

Schizopoda.—Certain shrimp-like forms occurring in the coal measures are now referred to this order, and amongst others are included *Pygocephalus cooperii*, from Lancashire; *Crangopsis*, from the Scottish coalfields; and *Anthrapalæmon*, from the South of Scotland, Lancashire, and the Illinois coalfields, U.S.A.

Ostracoda.—Ostracoda are abundant in most coalfields, and long lists of species have been recorded. The chief genera are *Leperditia*, *Beyrichia*, *Carbonia*, *Candona* and *Bairdia*. Wherever ostracods occur, they do so almost invariably in abundance, but their minute size causes them to be often overlooked. They serve, nevertheless, as useful guides to the miner.

Brachiopoda.—Several forms belonging to this group may easily be mistaken for minute brachiopods or lamellibranchs. *Estheria* has a wide range, being found in the English and Continental coalfields, and in America. *Leaia Leidyii* occurs in the English and American coalfields. It is worthy of note that the general arthroped fauna of the

English coal measures has rapidly increased of late years largely owing to the labours of Dr. Henry Woodward, and in all probability it will be still further increased as more careful search is directed to the coal shales.

MOLLUSCA.—The highest class of the mollusca, that of *Cephalopoda*, is represented in the coal measures by nautiloid

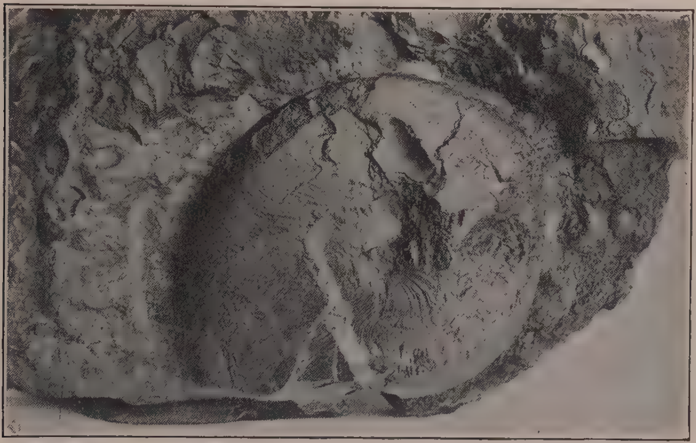


Photo.] [*J. Lomax.*

FIG. 8.—Block from roof of coal seam, containing a large Nautilus. (⅓ natural size.)

forms, such as *Coelonautilus*, *Discites*, *Temnocheilus*, and *Nautilus*, by straight-shelled forms belonging to the family *Orthoceras*, and by numerous species of *Goniatites*. The latter are now divided up into several families and genera, amongst the chief being *Glyphioceras*, represented by *G. truncatum*, *G. reticulatum*, *G. diadema*, and *G. paucilobum*; *Gastrioceras*, to which is referred the well known fossil formerly known as *Goniatites Listeri*, and a closely allied form, *G. carbonarium*, whilst *Dimorphoceras Gilbertsoni* is a

small flattened species occurring usually in colonies of many individuals. Very few of the cephalopoda pass up into the middle and upper measures, the great bulk of them being common not only to the lower series, but to the shales of the Millstone Grit below. A remarkable "marine band" in the middle coal measures occurs in the banks of the River Tame at Dukinfield, which has yielded a suite of fossils much resembling, and in some cases identical with, lower coal-measure forms. Amongst the cephalopod fauna are two or more species of *Discites*, *Nautilus precox*, and a species of *Goniatites*.

Gasteropoda.—The coal-measure gasteropoda have as yet attracted little attention, and very few satisfactory species are known. In nearly all cases the forms are small, and the shell ornament obscured by a thin closely adherent layer of shale. Provisionally they may be divided into three groups according to their form. The first and commonest are small turreted shells of from five to eight whorls, which have been classed with *Turritella*, *Loxonema*, *Macrocheilus*, *Melania*, and *Rissoa*. To the second group belong forms in which the last or body chamber is much swollen and the spire small and acute. These appear to be closely allied to *Natica* and *Naticopsis* To the third group belong shells of a *Bellerophon* type. Seven species of the latter are recorded from the English coal measures, and *Euphemus Urii*, from the middle series. The coal measures of South Joggins, Nova Scotia, have yielded several genera and species of land mollusca.

Pelecypoda.—Bi-valve mollusca are the commonest of all coal-measure fossils, the species of *Anthracosia* (*Carbonicola*), *Anthracomya*, and *Naiadites* (*Anthracoptera*)

being particularly numerous, especially in the middle measures.

The first of these often forms definite bands through the shales or ironstones, and are known as "mussel-bands." *Carbonicola* and *Naiadites* are fairly numerous in the lower measures, whilst *Anthracomya* is rare. In the middle series all the genera are well represented by numerous species, whilst only examples of *Anthracomya* and *Naiadites* pass up into the upper measures.

Carbonicola (*Anthracosia*).—A genus in which the shell is somewhat similar to the common mussel in appearance. The anterior part of the shell is usually somewhat swollen, whilst posteriorly it becomes narrow and at times angulated. The surface is marked with coarse concentric lines of growth. The umbones are tumid and frequently eroded.

The following are the chief species of *Carbonicola*, all of which are common to the lower and middle series. *Carbonicola robusta*, *C. acuta*, *C. rugosa*, *C. nucularis*, *C. aquilina*, *C. subconstricta*; *C. acuta* and *C. aquilina* occur in vast numbers in certain of the lower shales, whilst *C. robusta* is the species of the "mussel-bands" of the middle series.

Anthracomya.—A genus in which the shell is small and rounded anteriorly, the posterior end being expanded. The hinge line is straight and long. An oblique rounded ridge passes backwards and downwards from the umbones to the hinder inferior border. The surface is marked by fine concentric lines of growth, whilst the periostracum is often wrinkled. It is, with the exception of *A. Wardii*, a typical middle and upper coal-measures fossil. *A. Wardii*,

A. modiolaris, A. dolabrata and *A. minima* are confined to the middle series. *A. Phillipsii* is usually regarded as equally typical of the upper beds, but in the Somersetshire field has been found ranging downwards almost to the base of the coal measures. *A. minima, var. carinata*, and *A. lævis, var. Scotica*, are common to the middle and upper series.

Naiadites.—A genus in which the anterior end is comparatively small and stout, from which it expands to the hinder and inferior border. The shell is therefore very unequilateral, a feature which is strengthened by an oblique ridge rising from the umbones and dying out upon the inferior border. This genus is represented in the lower series by *N. modiolaris* and *N. quadrata*, which also pass up to the middle beds, where the following species also occur:—*N. Browniana, N. carinata, N. elongata*, and *N. crassa; N. Browniana* also occurs in the upper series of Lancashire.

Pterinopecten papyraceus is a pecten-like shell, marked with numerous radiating ribs. It is one of the most characteristic lower coal-measure fossils, being found in crushed masses in the shales, or uncrushed and well preserved in the roof nodules, commonly called "Bullions," of the Upper Foot and Union mines of Lancashire, and the Halifax Hard Bed of Yorkshire. Closely allied forms, *Pseudamusium fibrillosus* and *P. Cairnsii* occur in the "marine band" at Dukinfield.

The genus *Posidoniella*, in which the shell is unequilateral and mytiliform, is interesting as linking up certain of the shales below the Millstone Grit, with the latter and the lower coal measures. Several species are known, the most important being *P. lævis, P. minor, P. sub-quadrata* and *P. lævigata*.

FIG. 9.—Sigillaria.

The Pelecypoda of the coal measures have been fairly thoroughly described and figured by Dr. Hind in his Monograph on "*Carbonicola, Naiadites and Anthracomya*," published by the Palæontographical Society, which ought to be made use of by the student for determination of species.

Brachiopoda.—This large class, although well represented in the carboniferous limestone, is conspicuously weak in the coal measures, only two species having any importance.

These are *Lingula mytiloides*, which frequently occurs in abundance in the black shales of the lower measures, and *Orbiculoidea nitida*, which is common to the lower and middle series.

Vermes.—This division probably had a much greater development than is now evident, the wholly soft-bodied forms having left no trace of their presence, except by burrows and worm-tracks in the sandstones.

Spirorbis pusillus, which possessed a minute simply-coiled shell, was ubiquitous, ranging all through the series, and was often found attached to leaves and fronds.

Spirorbis helicteres is abundant in the upper series of Manchester.

Flora.

The character and relationship of the numerous fossil plants found in the coal measures is not yet fully understood, although considerable progress has been made in this direction. Many fruits, leaves, stems, and roots, which were formerly regarded as distinct genera and species have been shown by a study of their structure to be nearly allied, and in some cases identical, and many

fossils regarded as ferns are now believed to be the leaves of tree-like forms.

The study of the fossil flora may be said to have commenced by the labours of Brongniart and Grand'Eury in France, Hutton and Binney and Williamson in England.

FIG. 10.—Annularia.

It is during the last twenty years, however, that progress has been most marked, a powerful school of paleo-botanists having devoted themselves to the subject with remarkable results. Most of the material which has yielded these results has been obtained from the famous nodules or concretions sometimes termed "coal balls" of the lower coal measures of Lancashire and Yorkshire. The coal balls consist of irregular aggregations of plant remains, in

FIG. 11.—A fine specimen, probably the foliage of a Cycadian Gynmosperm.

which the most delicate tissues are often wonderfully preserved, bound together by earthy material and disorganised vegetation, richly impregnated with carbonate of lime, which will be more fully described later.

As the whole subject of paleo-botany at present stands, the student will find that one series of genera and species are founded upon exact structural details and true botanical relationships, whilst a second and older series of genera and species are founded upon the external forms and appearance of fruits, leaves, fronds, leaf-scars, stems, and roots. The labours of the present school of paleobotanists are resulting in the linking up of external features to internal structure, and in time it is almost certain that the great bulk of coal plants will be correctly understood, and that many now familiar names given to coal plants upon external characters alone will disappear, to be replaced by others founded by internal structure and natural relationship. This result is unavoidable, as it has been conclusively proved that in some cases the root, stem, leaves, and fruit of a single plant have received separate generic and specific names.

One feature which has not yet reccived the consideration it deserves is that of the stratigraphical succession of the coal-measure flora. The labours of Grand'Eury on the Continent, and the later work of Kidston in Great Britain, seem to show that it will yet be possible to determine stratigraphical sequence by the flora alone.

The flora of the coal measures consist chiefly of Lycopods, Calamites, Coniferæ, and Cordiates.

These grew with a profusion unknown since that time; slight and delicate herbaceous plants were no less numerous

FIG. 12.

than tall, outspreading ones, and have been preserved in many cases in great perfection. Of these beautiful plants the most common are Pecopteris, Alethopteris, Neuropteris, Sphenopteris, Odontopteris. The Lycopods were represented by the gigantic club moss Lepidodendron, which stood upwards of fifty feet in height. Many coals contain large quantities of the spores of this tree, notably the flaming coals. The fossil bark of the Lepidodendron is probably the most familiar of all fossil remains of the coal measures.

The Lepidophloios, Bothrodendron, Sigillaria, and its roots Stigmaria ficoides, etc., are also included in this class.

The Sphenophyllum class, although common in coal-measure times, are quite distinct from any other group at present known.

The Coniferæ, Cycads, and Cordiates, though not found in great abundance, must have formed a conspicuous feature of the carboniferous forests, with their stately trunks and long leaves.

This early period of plant life is well described by Hugh Millar. "All round us are the relics of innumerable forms of plant life which flourished and waved largely and luxuriantly in the warm breezes long before Egypt was dreamed of, or Nineveh ever knew Nimrod, or Athens knew Thesus or Athene, or Rome knew Romulus, or to begin aright, Adam knew Eve. Every tree and plant whose ruins are here compressed into these beds of coal was green, and was wood centuries and centuries before Eden had her first rose and Eve had her first walk amid the beautiful flowers. The age of the Pyramids

Fig. 13.

of Ghizeh is nothing compared with this great pyramid of coal. Long, long before that pyramid arose above the sands, these seams of coal were packed up close, arranged and ready for human discovery and further use."

The subject of Fossil Botany is dealt with more fully in a subsequent chapter.

CHAPTER V.

BOTANY OF THE COAL-MEASURE PLANTS.

The development of the science of Palæo-botany, that is, the study of fossil plants, especially those of the coal measures, has opened out a field of research which will eventually prove of great assistance not only in enabling the origin of large numbers of present.day genera and species to be traced, but in the identification of coal seams, and the correlation of the various coalfields of any single country and their connection with the coalfields of the world.

Palæo-botany, or fossil botany, is practically a new science. Thirty years ago there was really nothing known of it, and many of its pioneers are still living. These pioneers include the late Drs. Lindley and Hutton, the late Prof. W. C. Williamson, of Owens College, Manchester, the late Mr. George Wild, of Oldham, the late Mr. John Butterworth, of Shaw, Mr. W. Binney, of Manchester, and others, in a more or less degree, in this country. In France, M. Grand'Eury, Adolphé Brongniart, Dr. R. Zeiller, the chief engineer of mines, and the late Dr. Renault, of Paris. Also in Germany, Count Solns-Laubach, of Strasburg, Dr. Potonie, of Berlin, Dr. Sterzil, of Chemnitz, and others. It is to these men that geologists especially are indebted for revealing the wonderful beauty and perfection of the fossil remains of a bygone and prolific

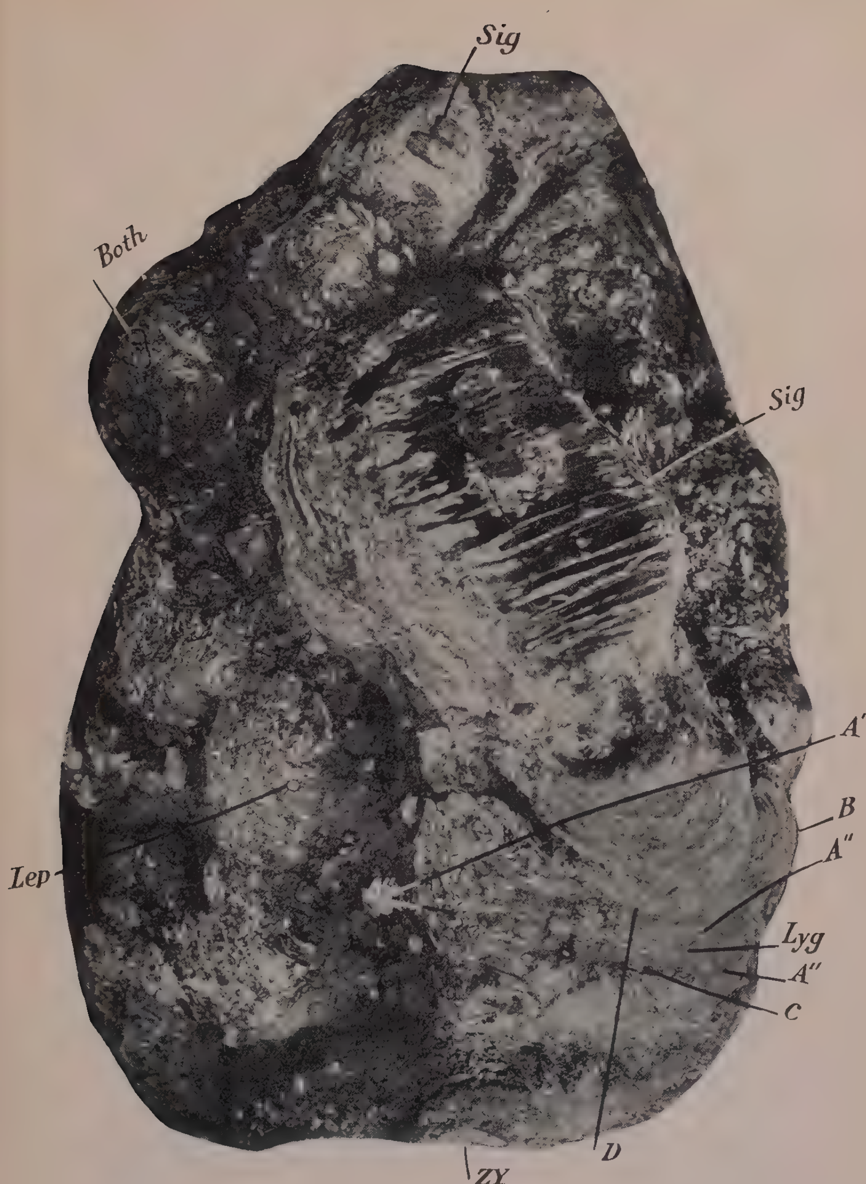
vegetation, which has never been repeated through all the subsequent years. These men introduced the present system of the study of Palæo-botany. This does not depend upon the outside shape of the impression or cast, but upon the internal or anatomical structure exactly as is done in the study of modern botany. The specimens collected and housed in museums usually show only the cast or impression of the outside, or part of a plant, a piece of a stem, a branch, the leaves, the fruit, the roots, or other broken and detached parts. It is seldom that a fossil plant is found complete in itself. This has caused some confusion in the naming and classification of fossils; in many instances the lower portions of the stem have been given one name, the upper portion another, while the leaf-stalk and the foliage have also been confused. Through the discovery of many specimens showing not only the outside or cast of the fossil, but the internal structure as well, the study of the plants of the coal measures is now more in keeping with the modern methods of practical botany. In many cases the structure is preserved so perfectly that it remains as it was when the plant was alive. Such specimens are not common, it is true: they occur only in a few isolated places, mostly in the lower coal measures, and in a few cases in the middle and upper measures. It is well known that all vegetable and animal tissues consist of various kinds of cells. Vegetable tissues consist of many shapes, sizes, and thicknesses of cells; some are round, others are almost square, others again are hexagonal, etc., some have ladder-shaped markings, some are formed like a pipe or tube of indiarubber, with a spiral thickening inside to keep the tube open, while others are like a bundle of small

tubes lying alongside each other with perforated sides. These various forms have been found in all plants from the time preceding the carboniferous age to the present time. The forms have been alike; the only difference has been in the arrangement and differentiation or characteristic qualities of the various species. We have already described the mode of formation of coal seams and coalfields, and with these in our minds, it is an easy matter to account for the preservation of some of these well-preserved plants, which ought, in the ordinary course of events, to have been carbonised or converted into coal. At the time of the formation of the seams, when, as has been said, large tracts of country and of forest were totally or partially submerged, the sea probably contained a greater quantity of lime, silica, etc., in solution than it does at present. The water formed into small lakes, pools, swamps, and lagoons, and these would be joined by small rivers or channels caused by the water running from a small pool at one elevation to another pool at a lower. The channels or goits thus formed varied in depth and width, no doubt, but in many cases ran through accumulations of the vegetable matter already described. During its course from place to place the water would gather pieces of this vegetable matter, roll them along, and thus make them more or less round. The surrounding ground also was undermined, letting in parts of large stems and roots, which also would become more or less round in their progress along the stream. At the same time petrifaction was going on. It is probable that in many places there were pools where a great amount of evaporation was taking place, leaving in many cases nothing but a pure lime-like solution of

carbonate of lime and silica. The material in which the petrified plant remains showing vegetative structure are enclosed, is always more or less round; they are composed, chemically, of carbonate of lime, carbonate of magnesia, bi-sulphide of iron, oxides of iron, and silica in varying proportions. They are always found embedded in or taking the place of the coal, thus showing that they have been deposited in the small streams or channels, cut through the decaying vegetable matter, which afterwards became a seam of coal. At Shore, near Littleborough, Lancashire, an excellent example of this is found in a mine owned by Mr. W. H. Sutcliffe, F.G.S. At certain points the coal seam is replaced by a bed containing nothing but the remains of petrified plants or nodules of this kind. In this way branches of trees, fruits, seeds, and other vegetation, which were dropped or blown into the stream, were petrified; in some cases delicate seeds, covered with the most exquisite hair-like filaments, have been perfectly preserved in every particular.

It will thus be seen that the Palæo-botanist can dissect, compare, or correlate fossil plants with those that are at present in a living state, and is enabled to trace the origin of a good many of the genera and species of modern plants. In the grounds of the South Kensington Natural History Museum there is a fine example of *Araucarioxylon Withami* (Lindley and Hutton), a petrified trunk of a large tree. This is one of two large stems found in the sandstone rock of Craigleith Quarry, near Edinburgh. When found it was about 35 feet long and nearly 4 feet in diameter in its thickest part. The other is in the Botanic Garden, Edinburgh. The tissues of these stems in places are fairly

well preserved, with the exception of the cortex, which is replaced by a thin coating of coal. This huge fossil tree was formerly supposed to be similar to the modern *Araucaria*, a type of which is the common garden ornamental tree, *Araucaria imbricata*, commonly known as the *monkey puzzle tree*, but really belonged to a distinct family. *Araucarioxylon* (or *Pitys*) *Withami* was, no doubt, a member of the Cordaiteæ, and very remote from *Araucaria*. Whether there is *any* affinity between them is a disputed question. The vegetative or internal structure of this fossil is in places fairly well preserved; the mineral matter consists of dolomite, with here and there a little silica. It is puzzling to account for the petrifaction of such huge stems, except in the manner suggested above. The trees have not grown on the same spot as found, but have been carried or conveyed from their original position by water, and during a portion of the journey petrifaction commenced, and was finished in the bed of sandstone as found in the quarry. If we return now to the petrifactions found in coal, we find a similar condition of things. In Plate I. we have a photograph of a number of nodular concretions, or "coal balls" composed of petrified plants, from the Upper Foot Mine, Lower Coal Measures, Dulesgate, near Todmorden, Lancashire. These nodular masses are embedded together similar to a conglomerate. The cementing material is usually carbonaceous matter, not always a true coal, more often a mixture of coal, iron pyrites, carbonate of lime, magnesia, and silica. In nearly all cases it is found that the cementing material takes a regular contour round the petrifactions, as if a quantity of vegetable pulp had been allowed to flow over a collection of pebbles till completely

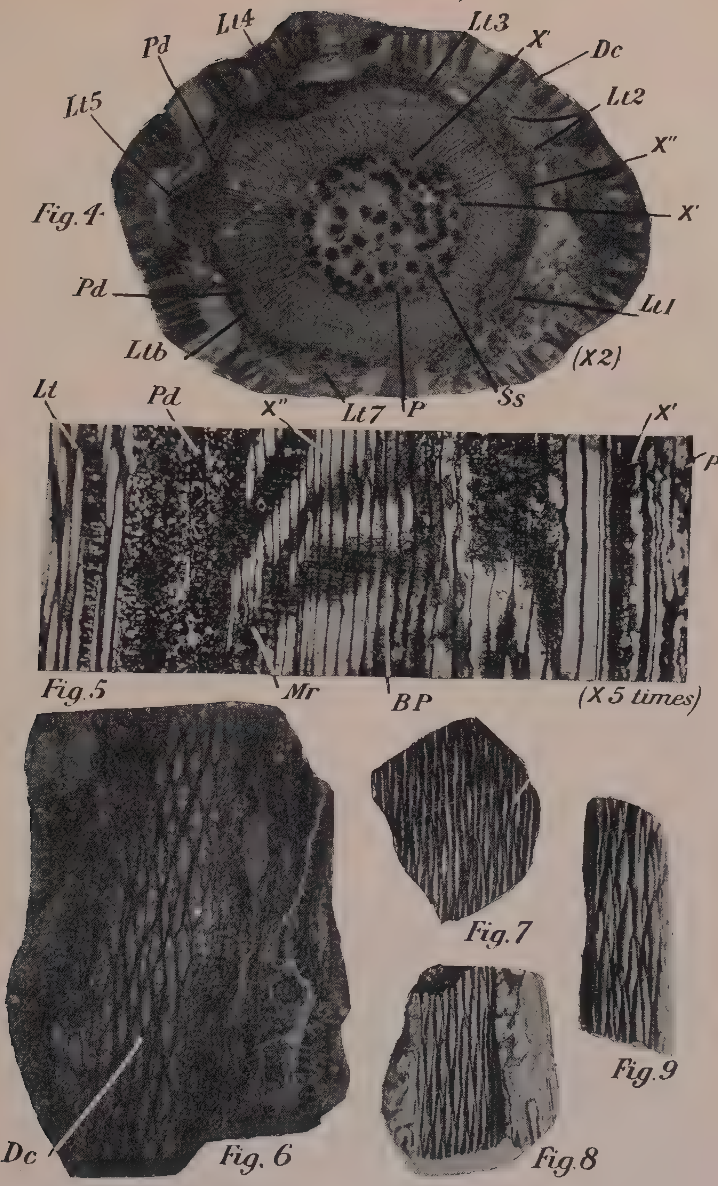


Photo] [*J. Lomax.*

PLATE I.
Calcareous nodule from Coal.

covered. The block on Plate I. originally measured about 1 ft. 6 ins. by 1 ft. by 1 ft., and the weight about 100 lbs. It was made up of a number of nodules of various sizes, the fossil contents of each one being different to its neighbour. At the top end (*Sig.*) there is a portion of the outer cortex of a stem of *Sigillaria elegans;* on the left, there is a nodule with a stem of *Bothrodendron* (*Both.*); lower down on the same side (*Lep.*) there is another nodule with the axis of a fruit *Lepidostrobus;* at the bottom end (*Zy.*) a fern stem is peeping out, *Zygopteris Bibractiensis;* on the right (*Lyg.*) there is a fine stem of *Lyginodendron Oldhamium;* higher up and nearly in the middle there is a portion of a large stem of *Sigillaria* (*Sig.*). By this it will be seen that a varied number of stems of different species is obtained, but in no case does the stem which is in one nodule continue into its neighbour, although this might have been expected if all the vegetable matter had grown and died *in situ.* The perfect state of preservation of some of these stems is wonderful, as, for example, the stem marked *Lyg.* on the right of the picture; this, on the surface, shows the outer cortex C, and the two ends A' and A''; the end A'' shows a branch being given off, which is marked B. When the specimen was cut transversely at the point D, and a transparent section made from it, the vegetable organs were revealed as shown in Plate II., Fig. 4.

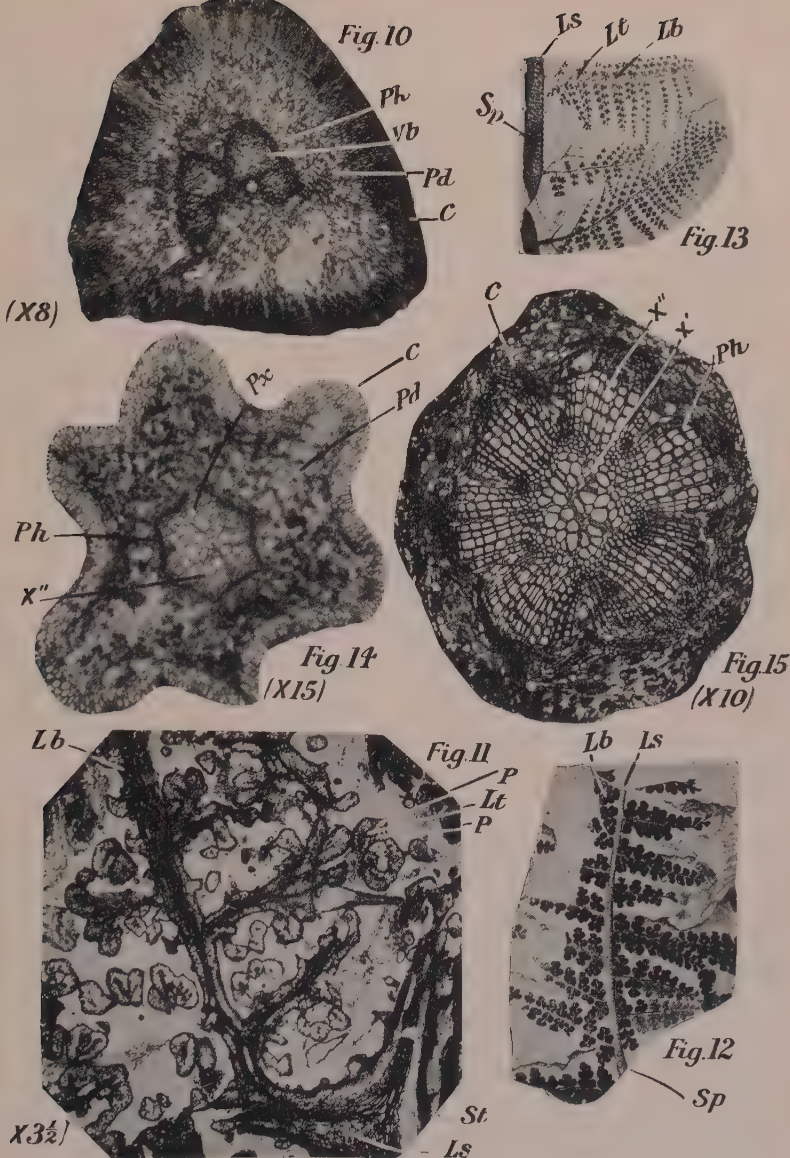
Lyginodendron Oldhamium.—It is not necessary to trace the growth of these fossil forms of plant life, but to give a general *résumé* of the position each one occupies in relation to existing plant life. The one now under consideration is one of the most common fossil plants we find in the Lower Coal Measures, and at the same time has been investigated



Photo] [J. Lomax.

PLATE II.
Pteridosperm : Lyginodendron.

in all its parts. A similar stem to this was first discovered by Binney in 1866, and fully described by Williamson in 1871, under the name of *Dictyoxylon Oldhamium*, afterwards changed to *Lyginodendron Oldhamium*, which is retained to the present time. Lyginodendron at first sight presents a structure in which Cycadean characters appear to predominate. Cycads are an order of Gymnosperm plants, *i.e.*, plants bearing naked seeds. These usually have simple or unbranching stems with pinnate leaves borne in a crown at top and fruits which are all of the simpler form of Gymnosperm type, though varying in structure and arrangement. The stems are exogenous in structure, *i.e.*, formed by having the wood augmented annually from outside. The pith is of considerable size, surrounded by a zone of wood and bast, with a layer of cambium (*i.e.*, a layer of delicate cells which separates the sap wood of an exogenous plant from the inner newly-formed bark) sometimes perfectly preserved between the two; the wood and phloem have a regular seriation resembling that of the corresponding tissues of a recent Cycad, but in and around the pith several distinct strands of primary wood are evident, which are not met with in the vegetative stems of Cycads. The primary zylem strands which are shown in Fig. 4, X', belong to the leaf trace system of the plant; they pass outwards through the secondary wood, X'', Fig. 4, into the pericycle, *Pd.*, which they traverse for some distance, forming themselves into complete bundles. When they leave the secondary wood they are one bundle only (*see* Fig. 4, Lt^1), but after traversing some distance in the pericycle they divide into two distinct bundles (*see* *Ltl*—2—3—4, etc.). *Lt.* 5 is the most advanced, and would in the ordinary course pass



Photo] [J. Lomax.

PLATE III.
Pteridosperm: Lyginodendron.

through the cortex *C*, and enter the leaf stalk, as shown in Figs. 10 and 11. Plate III., Fig. 10, is a transverse section of the leaf stalk showing the two bundles (*Vb*) together forming a rough V-shaped mass of vascular tissues; *Pd.* is the periderm; *Ph.* the phloem; and *C*, the cortex.

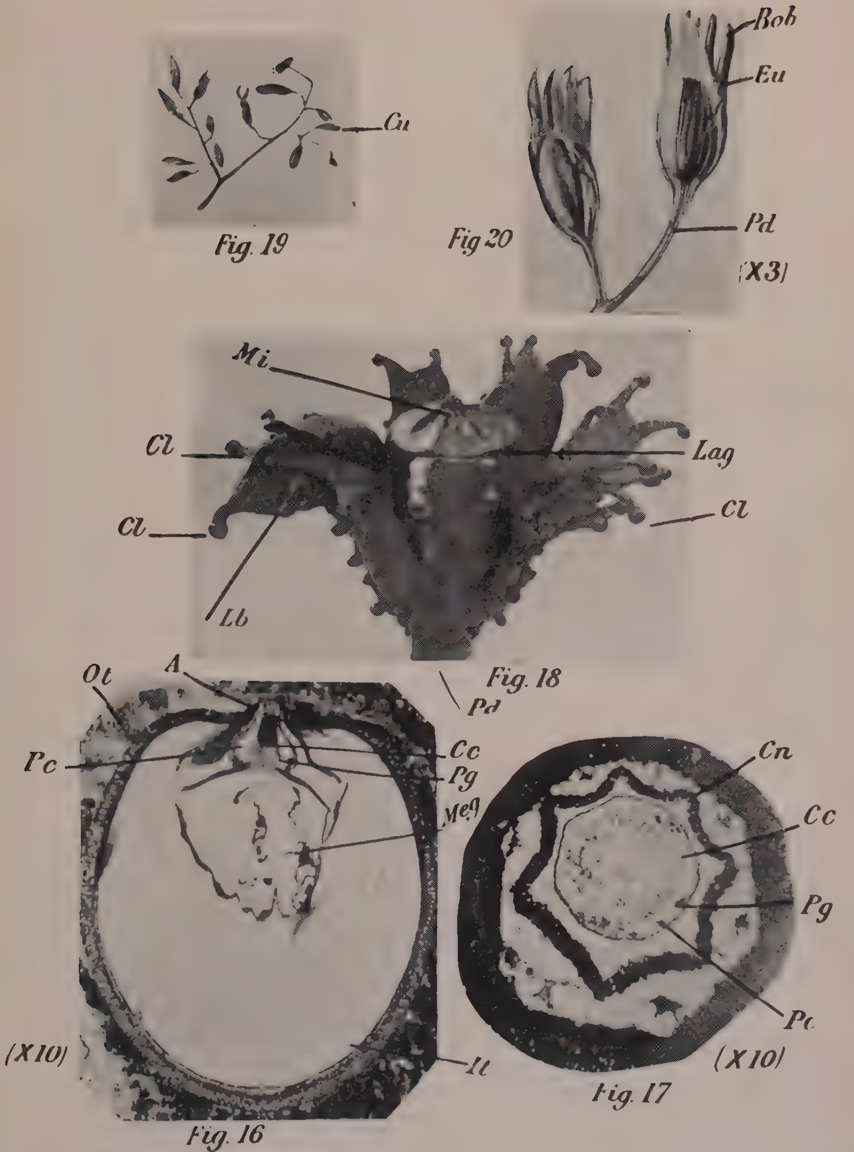
In Fig. 11 is shown a vertical section of part of the main stem, *St.*, with a leaf stalk, *Ls.*, and foliage attached; *Lb.* shows a leaf with pinnules or leaflets, *P.* The foliage corresponds in many ways to that of a fern, and had in fact been acknowledged as a true fern until the end of 1899. In some of the young stems, before the secondary thickening commences, the resemblance to the stem of an *Osmundaceous Fern* (*Royal Fern*) is very striking. The foliage has long been recognised as identical with that of *Sphenopteris Hœninghausii*, two species of which are shown in Figs. 12 and 13. On the main stem or rachis of these two specimens, *Sp.*, will be seen a number of protuberances or outgrowths: these are also to be seen on Fig. 13. These outgrowths are characteristic of Lyginodendron. In young shoots and stems the cortical (*i.e.*, the outside or rind) tissues are almost always covered with long hair-shaped bodies, which are long and delicate with a knob at the end (*see* Figs. 21 and 22, Plate V.); similar bodies, too, are represented on the restoration of the fruit (Plate VI., Fig. 18); the function of these bodies is not exactly known, but undoubtedly they were of the nature of glands.

The leaf trace bundles of Lyginodendron have precisely the same structure as the foliar bundles of recent Cycads; the vessels of the woody portion of the stem also resembles Cycads. They are characterised by having numerous

bordered pits (*BP.*, Plate II., Fig. 5). This gives a general idea of a radial section of the stem. *P.* is the edge of the pith, *Mr.* are the medullary rays, *Lt.* are leaf trace bundles, *Pd.* peridum, and *BP.* are bordered pits. The branching of the stem was very frequent in some specimens. The roots were mostly casual or adventitious, being given off from various parts of the stem, and in many cases branching repeatedly immediately after leaving the stem, these again giving off numerous small rootlets. The structure, too, of these roots, especially when young, had a somewhat marattiaceous character (like those of Marattiaceous Ferns), but on undergoing secondary growth assumed the structure of the root of a Gymnosperm. The root was first described by Dr. W. C. Williamson as being distinct from any Lyginodendron. He then named them *Kaloxylon Hookerii*. In Plate III., Fig. 14, there is a transverse section of an almost perfect young root, which shows the primary and secondary wood very well; *Px*, *X″*. Fig. 15, too, is perfect; this is in structure almost identical with some of the modern Gymnospermous roots, such as *Pinus Sylverstris*, etc.; the roots freely branched and gave off numerous rootlets. Towards the end of 1901 the vegetative structure of the stem was fully demonstrated. In the following year definite evidence was first obtained as to the nature of its seeds, or reproductive organs. Many years ago the outgrowths, or glands, mentioned above, were frequently noticed, and ultimately it was through the glands that the seed was found. Prof. F. W. Oliver[1] was the first to identify the

[1] See Oliver and Scott on *Lagenostoma Lomaxi* ("Proceedings of Royal Society," Vol. 71, 1903, and "The Phil. Trans. Royal Society," B, Vol. 197, 1904).

seed of Lyginodendron by means of the glands on the cupule. Mr. James Lomax then made a systematic search for other evidence, with the result that he got other specimens which confirmed Prof. Oliver's conclusion that the seed named by Dr. W. C. Williamson in certain manuscripts *Lagenostoma Lomaxi*, was the seed of Lyginodendron. The seed when found was enclosed in an outer envelope, or cupule, bearing numerous capitate glands, *i.e.*, glands possessing a head, or spines, identical with those in form and structure so often found on the vegetative organs of *Lyginodendron Oldhamium*, and with which the seeds are constantly associated. There is no other fossil plant known with similar appendages, and the evidence of the glands alone would be sufficient to justify the attribution, considering the close association of the vegetative and reproductive organs in question. Further anatomical evidence is supplied by their internal anatomy. The vascular or arterial bundle of the pedicel, or stem bearing the seed, has the same structure as a small leaf stalk or rachis of Lyginodendron, while the smaller bundles which traverse the cupule, *i.e.*, the husk or shell, agree with those in the lamina of the vegetative leaflets. Fig. 18, Plate IV., is a restoration of the cupule and the seed: *Lag.*, the Lagenostoma or seed; *Mi.*, Micropyle or mouth of the opening of the ovulum; *Cl.*, glandular bodies; *Lb.*, lobes of cupule; *Pd.*, the pedicel or foot-stalk of the seed. The above figure is reproduced from a model made by Mr. H. E. Smedley, under the instruction of Dr. F. W. Oliver, after a study of more than one hundred seeds, etc., found and prepared by Mr. James Lomax. Plate IV., Fig. 16, is a vertical section of a mature seed, *Lagenostoma Lomaxi*,



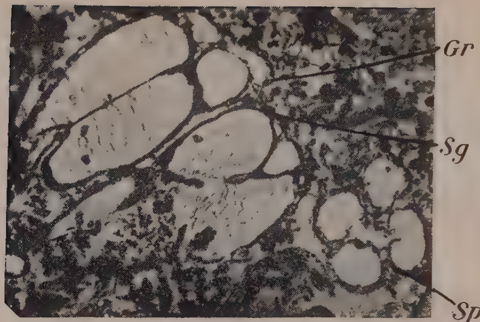
Photo] [J. Lomax.

PLATE IV.

Pteridosperm : Lagenostoma ; seeds of Lyginodendron.

which is cut through the micropyle *A.*, the central column of the nucellus *Cc.*, the pollen chambers *Pc.*, pollen grains *Pg.*, and the megaspore, *Meg.*; *It.*, the inner testa, or covering of the seed and the palisade layer or outer testa *Ot.* Fig. 17 is a transverse section of a seed similar to the last, cut through the base of the pollen chamber. The nucellus in this section is well shown; on the periphery of the column there are several pollen grains lying in contact (see *Pg.*, Fig. 16). A fully matured *Lagenostoma Lomaxi* would be about the size of a small pea. The shell, or testa, was a fairly strong one, made up of the palisade layer, which is well shown in Fig. 16; this layer had also, in some of the seeds, peg-like protuberances attached to it, which gave it a rough outward appearance. The apex of the seed was slightly depressed in the centre, in which depression the micropyle was situated. In the micropyle was the orifice of the pollen chamber, which was bounded by the annular pollen chamber, *Pc.*; in the centre of this rose the central column of the nucellus, *Cc.*, which extended a little above the outer layer of the testa. In this position it would most readily come in contact with the male reproductive organs. In these two seeds (Figs. 16 and 17) there are several pollen grains in contact with the central column. The apex of the seed, as in the recent Cycads and Ginko, contains the pollen chamber and nucellus; below this is the megaspore or embryo-sac. The seed was of complex organisation, and shows that Lyginodendron, in spite of its fern-like characters, had attained a position very near the Cycads. The structure of the pedicel indicates that the seed was borne on a foliar branch, but the exact position is not known. The evidence goes to show that the seeds were borne on modified

fronds or pinnæ of a compound form. In Fig. 23, Plate V., we have another seed of Lyginodendron, viz., *Physostoma elegans*, which differs somewhat from *Lagenostoma Lomaxi*, the testa in this being covered by numerous hair-like bodies, similar in some respects to those glandular bodies found on the leaf stalks and stems (*see* Figs. 21 and 22). In Fig. 23 they are well shown, especially near the apex, *A.*; these bodies have a columnar arrangement round the testa which, when seen in trans-section (*see* Fig. 24), give it the appearance of a small flower. A good transverse section from a well-preserved specimen is undoubtedly one of the most beautiful of the coal-measure petrifactions. Figs. 23 and 24 show a number of hair-like bodies, *A.*, *A.*, in transverse section; *M.* (Fig. 23) is the apex of the micropyle with two of the columnar bodies in vertical section; *Nu.*, the nucellus; *Pc.*, the pollen chamber. In 1877 Stur described a form of fructification under the name of *Calymmatotheca Strangerii* (Fig. 25), belonging to a so-called fossil fern, *Sphenopteris Hœninghausii* (*see* Figs. 12 and 13, Plate III.), which has now been proved to be the foliage of *Lyginodendron Oldhamia.* This was of the lower carboniferous age, as also are the seeds in question. Fig. 25, Plate VII., is a drawing from the original specimen by Miss Woodward. It represents a fertile frond bearing a number of deeply lobed cupules, borne on a naked branching rachis. These are undoubtedly lobed cupules or indusia. Some Palæo-botanists have maintained that they are sporangia. There is but little doubt that they are of the same nature as the cupules of *Lyginodendron Oldhamium*, from which the seeds have been shed prematurely. A seed has been lately figured and described by Mr. Arber, *Lagenostoma Sinclari* (Kidston), evidently



(X10) Fig. 26

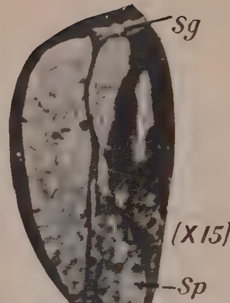


Fig. 27

Fig. 22

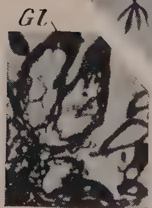


Fig. 21

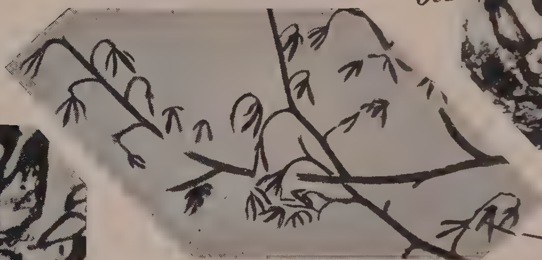


Fig. 25 (Slightly reduced)

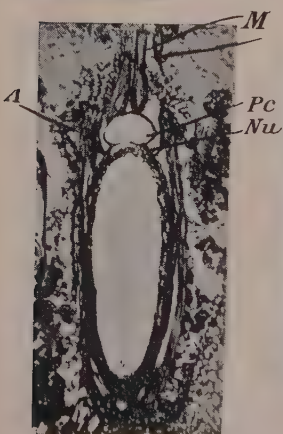


Fig. 23 (X 2½)

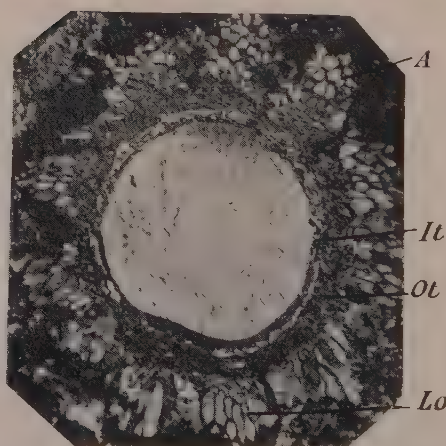


Fig. 24 (X8)

Photo] [J. Lomax.

PLATE V.

Pteridosperm : Seeds and Microsporangia of Lyginodendron.

allied to the seed of Lyginodendron, and like the latter, it is invested in a cupule: these are figured on Plate IV., Figs. 19 and 20. M. Grand 'Eury, in France, has observed six lobed cupules, in some cases still retaining seeds. So far we have dealt with the female reproductive organs only. Mr. Kidston's important discovery of the male organs, *Lyginodendron Oldhamia*,[1] has completed the information on this important fossil plant. The fertile pinnules occur on the same fronds which bear the ordinary vegetative leaflets, so that he was able to demonstrate direct organic connection with the foliage of Lyginodendron. The sporangium with microsporangia was first described by Miss M. Benson[2] in 1904 under the name of *Telangium Scottii*. This fructification had the structure preserved, and in many cases the sporangia contained microspores. On Plate VII., Figs. 26 and 27, will be seen two groups of these sporangia. Fig. 27 shows two long sections of the sporangia containing many spores, *Sp. Gr.* (Fig. 26) is a group of sporangia just as detached from the fertile frond, cut a little obliquely, the four others, *Sp.*, near these, being cut transversely. The form of the sporangia in long section was similar to those of Fig. 27, and in transverse section similar to the four sporangia in Fig. 26, *Sp.* From four to eight of these sporangia would be joined together to form a synangium (grape-like clusters), which would be borne on a fertile branch, and hang downwards from the pinnæ. The pollen which they contain agrees with most of those found in the pollen chamber of Lagenostoma. There is little doubt that *Telangium Scotii* is the male organ of

[1] "Phil. Trans. Royal Society," Series B, Vol. 198, 1906.

[2] "Anns. of Botany," Vol. 18, 1904.

Lyginodendron Oldhamium. The position which this genera occupies in the modern classification of plants is a stage intermediate between that of Cycads and Ferns. Professor Potonié, of Berlin, some time ago proposed the name of *Cycadofilices* for the group, and this has been accepted. The highly organised seed strongly indicates Cycadean affinities, and the microsporangia of the fructification is entirely fern-like in its nature. The Lyginodendron and several other fossil coal plants which have fern-like foliage and highly organised seed have therefore now been grouped together as a distinct order, under the name of *Pteridosperma*, or fern-like plants with proper seeds.

In the foregoing portions of this chapter a genus of fossil plants has been dealt with occupying a position botanically which no *modern plants* occupy. All fossil impressions possessing foliage resembling that of a fern were formerly classed as belonging to the true *Filices* or Fern family. Such was not the actual case; evidence has been gradually accumulating which proves that a large portion of the so-called Palæozoic plants, commonly classed as ferns, were in reality seed-bearing plants. For a number of years it has been the custom to speak of the Palæozoic period as the reign of the *Higher Cryptogams*. This is not correct, however, as new evidence is almost daily being obtained restricting more and more the limits of the true ferns, and annexing many of them to the Spermophyta or seed-bearing plants. There is some doubt as to whether 20 per cent. of the "Fern Fronds" of the carboniferous period offer any real evidence of having been true Cryptomic Ferns, while the rest, or at least 50 or 60 per cent., are in all probability fern-like seed-plants.

Besides the above we have the Lycopodiaceous, or cone-bearing fossil plants of the carboniferous period, such as the Lepidodendroid, Sigillarian and Bothrodendroid types, which have all been classed as belonging to the modern vascular cryptograms, such as the modern Lycopodiums and Selaginellas; latterly Palæo-botany has brought forth evidence which throws great doubt on these conclusions.

Dr. D. H. Scott, in his memoir on the seed-like fructification of Lepidocarpon,[1] shows that some of the reproductive organs—such as the embryo-sac enclosed in an integumented or coated sporangia (see p. 63)—do not belong to the true Lycopods. Again, Miss M. Benson[2] shows the same features in the case of Miadesmia seed, each of which *contains a true seed*. There is no doubt that some of the Lycopods of those early coal-measure days were highly organised plants, and had in some cases acquired—on lines of their own—something very like the seed habit of re-production, and such as we find in modern seed-bearing plants.

One striking and remarkable genera of Lycopodiaceous fossil plants, which has had little attention paid to it, is Bothrodendron. Many impressions of this genera have been found, but few are available which show the internal and external structure combined in such a way as to allow of the correlation of the two kinds of fossils (the impressions and petrifactions together). Mr. Lomax in 1903, however, found several specimens by which he was enabled to do this, and these will be more fully described.

[1] Mr. D. H. Scott, 1901. "The seed-like Fructification of Lepidocarpon" ("Phil. Trans. Royal Soc.," B., 94, 43 pp., 6 pl.).

[2] Miss M. Benson, 1902. "On a new Lycopodiaceous seed-like organ" ("New Phylologist," Vol. 1, 2 pp., 1 fig.).

Bothrodendron.—Bothrodendron belongs to a genus of fossil plants founded by Lindley and Hutton[1] in 1827 from a few specimens found in the roof of the High Main Seam, Jarrow Colliery, Durham. In their description they say "they are the remains of some large plant of which the scarred stems, and the bodies that belong to the scars alone are left. Good casts of Bothrodendron are amongst the most striking of Fossil Plants."

Plate VI. is a photograph of a specimen in the Chadwick Museum, Bolton, which was obtained from the middle coal-measures at Walkden, near Manchester. It is similar to the one figured by Lindley and Hutton.

The surface of the stem is slightly wrinkled in appearance, the wrinkles being caused by a number of fine longitudinal striations. There are also numerous small dots, arranged in a quincuncial manner, varying in distances apart, according to the size and age of the stem. These dots are the remains of the leaf bases, to which a rather long lanceolate leaf was formerly attached. These are well shown in the specimen at *Lt.*, Plate VI. The dots or cicatrices show the position of the vascular or foliar bundle which gives the specimen a punctured appearance. The type specimens were named by Lindley and Hutton *Bothrodendron punctatum*, chiefly on account of the punctured appearance of the cortex or outer bark, through the occurrence of numerous foliar bundles (*see* Plate VII., Fig. 30, *A*) on the surface. On the upper edge of the scar there is a small dot, or more correctly, a pit (*lig.*). This represents the point at which the ligule was fixed, and is seen more

[1] Lindley and Hutton, "Fossil Flora of Great Britain," Vol. 11, p. 80, 1833.

Photo.] [J. Lomax.

PLATE VI.

Lycopodinae: Bothrodendron punctatum.

clearly in Fig. 33; which is a drawing of a longitudinal section of a stem showing the position of the leaf and ligule, attached to the outer cortex. Besides the leaf-scars there are often large and circular concavities, arranged at intervals on opposite sides, varying much in size, some being over 5 inches in diameter. Two are shown on the specimen, Plate VI. The one *A*, at the lower end, is a very good one, and is $4\frac{1}{2}$ inches in diameter. The one *B*, at the top, is rather smaller. Each scar or depression has a fractured surface, which suggests that something has been broken off. It has been assumed that these scars bore a fructiferous cone or fruit. The amount of depression around the edges of the cavity is about three-quarters of an inch below the surface of the stem; the centre of the scar rises about level with the surface of the stem. The two scars are from centre to centre exactly 12 inches apart. The small dots are well shown at *Lt.*; they are on an average three-eighths of an inch apart. It is evident that this specimen is a fragment from a very large stem, the probability being that it is the upper part of the trunk. By the appearance of this and other specimens examined by Mr. Lomax, he has come to the conclusion that these specimens are portions of trunks which bore a large amount of foliage and numerous fructiferous branches. It is common to find similar impressions marked only with the small dots, with a total absence of the large scars. In many cases these have not been greatly noticed, owing to their smooth appearance, but in all probability they are portions of similar trees from the lower or unbranching parts.

Besides the above species of Bothrodendron there is

Photo.] [*J. Lomax.*

PLATE VII.

Lycopodinae : Bothrodendron punctatum and minutifolium.

another, viz., *Bothrodendron minutifolium*, specimens of which are only small in comparison, and are always found covered with small lanceolate leaves (*see* Figs. 28 and 31). These specimens are considered to have been the foliage branches of some larger stems of Bothrodendron. Dr. R. Zeiller, the well-known French Palæo-botanist, figures in his atlas,[1] (Fig. 1, Plate LXXVI.) a specimen of *Bothrodendron minutifolium*, which is reproduced on Plate VII. Fig. 28. The lower part of this specimen has the characteristic and dotted appearance of the large stem in Plate VI., whilst the upper part consists of branches which dicotomises and ultimately gives off altogether twelve smaller branches. These upper branches are covered with small lanceolate leaves.

Fig. 29 is an enlarged drawing of these leaves. The small dots, or leaf scars, of the lower or main stem, are shown in the enlarged drawing, Fig. 30. When the specimen (Fig. 28) is examined minutely it is found that there is a gradual falling off of the leaves from the lower part *A*, to *B* or thereabouts, on the upper part; this is accounted for by the basal part of the leaf being small and having only a small surface attachment. The structure and shape of the leaf are similar to the recent Selaginella. Fig. 31 is a slab of sandstone from the middle coal-measures which contains a number of impressions of *Bothrodendron minutifolium*. Associated with these are several large flattened stems, with a surface similar to Plate VI., but without the larger scars. These may possibly have been small branches similar to those in the upper part of Fig. 28.

[1] "Vegetaux Fossiles Du Terrain." Houiller, *La France*, Plate LXXVI., Fig. 1.

We have so far dealt with the impressions of Bothrodendron. If we now turn to Fig. 32, Plate VII., we shall find a similar specimen to the lower or main stem of Fig. 28. This is almost perfect, and shows the vegetative structure in a similar condition to those already figured of Lyginodendron. This specimen was discovered by Mr. Lomax in 1903 in one of the petrifactions from the Upper Foot Mine, Dulesgate, Todmorden. The total length, including the branches, was about 8 inches. The diameter of the thickest part was about $1\frac{1}{4}$ inches. At a short distance from the broad end the stem divided into two parts, these again divided, making altogether eight small branches.

Fig. 34, Plate VIII., is a transverse section of a stem similar to Fig. 32. This stem shows a thick outer cortex, composed of strong thick-walled cells. The epidermal layers are slightly striated longitudinally, with the leaf scars at regular intervals. The latter are clearly shown in Fig. 32, *Lt.* The leaf scars are in the shape of a very small tubercle (*i.e.*, a knob or swelling), with a central pip or point, which corresponds with the leaf trace bundles before mentioned (see Fig. 30, *A*), which is much enlarged. On the upper edge of the scar there is another small dot, or more correctly a pit, *lig.*, which represents the point at which the ligule was fixed. This is seen more clearly in Fig. 33, which is a drawing of a longitudinal section of a stem made to show the position of the leaf and ligule, attached to the outer cortex. The point, *lig.*, in the axil of the leaf shows the ligular pit with the ligule; *Vb.*, the foliar bundle; *Ep.*, the epidermis of the stem; *Pd.*, the periderm; *Med.*, medulea or vascular axis.

In the next plate, VIII., Fig. 34, a transverse section is shown, cut from a similar stem to Fig. 32. This is almost perfect; the medulla is shown enclosed in the medullary sheath, *Ms.*, which consists of a number of small and short fibro-vascular cells, on the outer edge of the medulla, *M.*; there is a number of small bundles, consisting of seven or eight minute vascular cells, which are given off from the medullary cylinder at regular intervals. These are shown better in Fig. 35, *Lt*; they pass outwards through the periderm, inner cortex, and outer cortex, to the leaf bases, *Lb.*, in Figs. 37 and 38. Immediately on reaching the base of the leaf, the ligular pit is formed, with the leaf trace bundle below. In some of the leaves the leaf trace extends almost to the tip, broadening out on its way; and, surrounded by transfusion tissues, on each side of the leaf trace, lie the parichnos strands. The position of the leaf trace is shown in Fig. 37, *Lt.*; the parichnos strands, *Pr.*; and the ligular pit, *Lig.* The stele and medullary axis consists in young stems of a solid vascular bundle of seven or eight cells in diameter. Two of these small stems are shown just after branching in Fig. 36, with the axil cylinders solid. After the axis becomes about ten cells in diameter it begins to develop a vascular cylinder with a pith cavity: this is well shown in Figs. 34, 35, and 38. The transverse section, Fig. 35, is a section cut from the same specimen as Fig. 34, but higher up the stem, at a point where the medullary axis has divided to branch or dicotomise. The cells of the pith are cylindrical and long, with almost square ends: these are well shown in the longitudinal section, Fig. 38, at *P.* The vascular cylinder itself consists of one or more rows of comparatively large cells. In young stems just after the

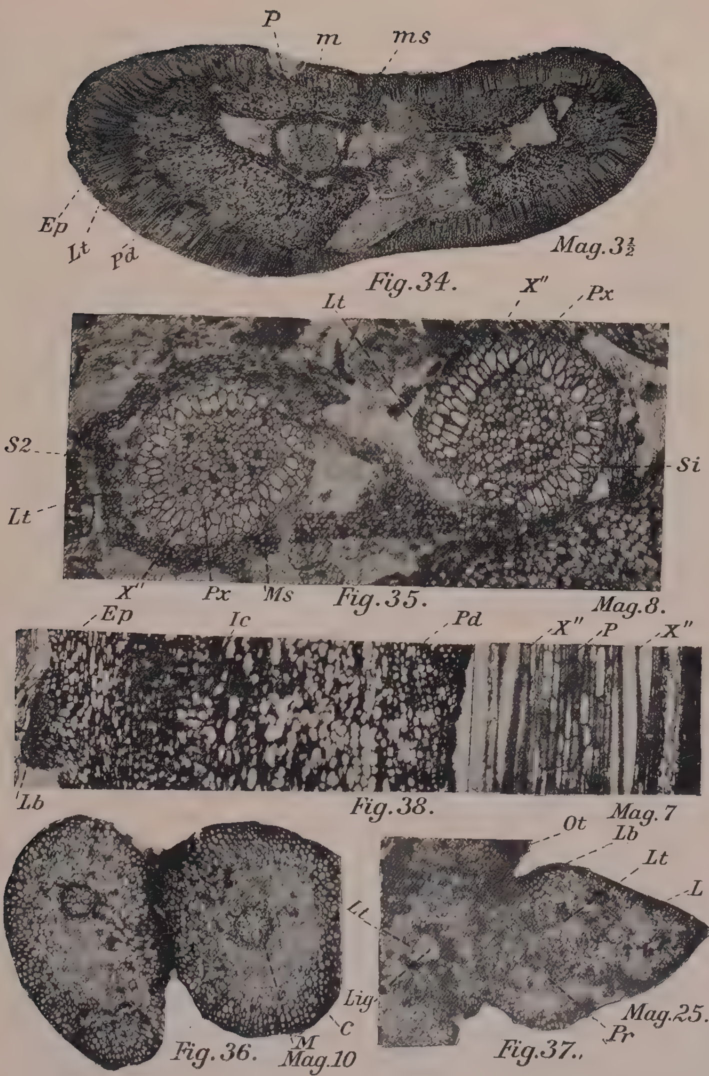


Photo.] [J. Lomax.

PLATE VIII.

Lycopodinae : Bothrodendron punctatum and minutifolium.

development of the pith they are usually not more than one cell thick, and large stems such as Fig. 32 (which is about $1\frac{1}{4}$ inches in diameter) are not more than two or three cells thick. The development of the axis, in diameter, is small in proportion to that of the outer or corticle part of the plant, as the thickness of the external part of the vascular cylinder is seldom over three or four cells in the largest specimens. Surrounding the vascular cylinder there is a small fringe of smaller vessels from which the leaf trace bundles are derived.

The late Dr. W. C. Williamson,[1] of Owens College, Manchester, was the first to point out the gradual development of a medulla within the interior of a vascular bundle, where in the youngest state of the bundle no trace of cellular tissues could be discovered. Dr. Williamson described and figured similar specimens to those of Fig. 36 as *Lepidodendron mundum;* more recent investigation shows that they are small twigs of *Bothrodendron punctatum*. After the pith had once commenced to grow it increased very rapidly, as will be seen on examination of Figs. 34, 35, and 38. The periderm or inner cortex of *Bothrodendron punctatum* consists of a number of fine parenchymatous or pithy cells (*see* Fig. 34). The diameter of the cells becomes less from within outwards, and as they do so, they gradually change into a closed celled prosenchyma with thickened cell walls, until the epidermal tissues of the cortex become almost solid. This is shown in the epidermal tissues of Figs. 34 and 38, *Ep*. It may not be out of place here to mention that the epidermis or cuticles of Bothrodendron have been

[1] "Phil. Trans. Royal Society," Vol. 180, 1889, B., Mem. XVI., p. 197, Figs. 7-14.

found in a remarkable state of preservation at Tovarkovo, in the province of Toula in Central Russia, in beds of a peculiar kind of coal, called *Leaf or Paper coal*, which have for a long time been known to geologists. The seam is about 8 inches thick and lies near the surface of the ground, being covered only by a bed of sand. This so-called coal has the appearance of excessively thin dead leaves intermixed with structureless organic matter of the nature of Humic acid. The leafy films have proved on examination to be layers of cuticle belonging to ancient plants, from which all other tissues have been lost through decay. The cuticles are quite fresh and pliable and not in any way fossilised, although (as geologists agree) the beds belong to the carboniferous formation. In some cases the cuticle is complete, corresponding to the whole circumference of the stem it once enclosed. These leafy cuticles are perforated by numerous small round holes, regularly arranged and corresponding to the leaf trace of a Bothrodendron. In some of the stems of Bothrodendron which Mr. Lomax has had under examination, he has found many which have lost their internal tissues before petrifaction and which correspond in every particular to those found in the leaf coal of Russia. (*In Fig. 48, Plate X., will be found a drawing of a similar piece to the leaf coal showing layer on layer of cuticles and leaves.*) There is no doubt that Bothrodendroid stems played a very important part in building up the vegetable *débris* which has carbonised into coal seams. The leaves, too, would play a no less important part, as all the stems, at one time or another, would be clothed with leaves, which would be shed in the early life of the plant, leaving, in the case of *Bothrodendron*

punctatum, a naked stem. The sessile leaves, *i.e.*, leaves which grow directly from the stem without a footstalk, would be easily detached. In the most slender twigs it is seldom that any of the leaves are found attached to the cortex. Fig. 37 is a portion of the cortex of a very young stem slightly over one-eighth of an inch in diameter; the leaf is shown almost flat, with the leaf trace, *Lt.*; parichnos strands, *Pr.*; and the ligular pit, *Lig.*; which is in the cortex and near the epidermis. If a leaf is cut transversly about the centre or middle of its length, it will show the same structure as Fig. 39, Plate IX. This section shows the vascular or leaf-trace bundle in the centre of the leaf, *Vb.*; the leaf of the parichnos, *Pr.*; the cuticle of the leaf resembles in structure that of the cuticle of the stem already mentioned; the parichnos had probably decayed before petrifaction. The length of some of the leaves must have been considerable, as one, attached to a stem of about one quarter of an inch in diameter (*see* Fig. 45, Plate X., *Lb.*), measured over 1¼ inches in length. One reason that leaves are seldom found attached to the cortical tissues in petrified stems is, that after being detached from the main trunk or branch, they would be rolled about, and the leaves having only a very tender ligament or mode of attachment to the stem, would be torn off. In case of many impressions this would not happen, as the stem, branch, or twig would in many cases be embedded in mud and preserved as an impression. That is one reason why so many impressions of small stems and twigs of *Bothrodendron minutifolium* are found with the leaves intact. The reproductive organs of Bothrodendron have been assumed to be similar to those of a modern Lycopod. In 1889 Mr. R. Kidston described and

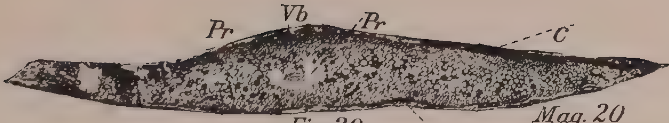


Fig. 39.

Fig. 49 reduced

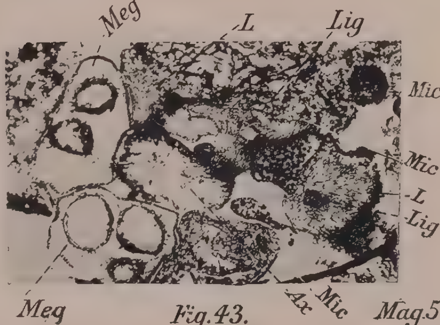


Fig. 43.

Fig. 41.

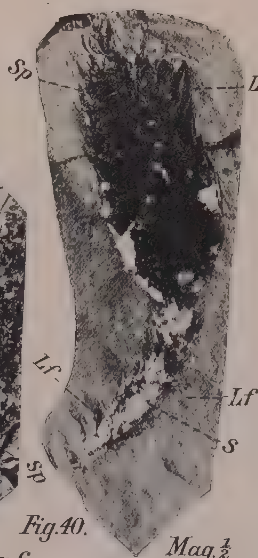


Fig. 40.

Photo.] [J Lomax.

PLATE IX.

Lycopodinae : Bothrodendron minutifolium.

figured[1] a specimen of *Bothrodendron minutifolium* from the Middle Coal Measures, near Barnsley, Yorkshire, with a male cone attached. The cone was long and narrow, and at that time it was the only known specimen of *Bothrodendron minutifolium* with the fruit. Since then several other specimens have been found, one of which is in the possession of Miss M. Benson, Royal Holloway College. This was discovered by Mr. Lomax and was heterosporous, that is, it bore both male and female sporangia. Afterwards Mr. Lomax found amongst some specimens from Sparth Bottoms, Rochdale, in Mr. W. H. Sutcliffe's collection, a beautiful specimen of a stem of *Bothrodendron minutifolium* surmounted by a portion of a male cone (*see* Plate IX., Fig. 40). In the upper part the microsporangia, *i.e.*, the small sack-like clusters, and lamina are exceedingly well preserved, the small portion of the stem beneath the cone agreeing with those figured on Plate VII., Fig. 31. Portions of other cones besides the above have been found by Mr. Lomax, which show the internal or vegetative structure. A transverse section of one is given in Plate IX., Fig. 41; this, before being cut, was about 1 inch in length, and was obtained from near the apex. Some of the sections are cut through the apex, showing the transverse arrangement of the lamina. On Plate X., Fig. 42, there is an enlarged section of this portion showing the axis, *Ax.*, composed of a number of vascular tracheides or spiral vessels similar to that of a young stem of Bothrodendron; *L* is the distal end of the lamina; at *Lig.* there is a fine ligule shown in its pit. *Bsh.* is a fine example of the basal part of a sphorophyll, with

[1] From the *Annals and Magazine of Natural History*, July, 1889, Fig. 6.

the sporangial walls attached, *Spw*. *Lt.* are leaf trace bundles. Some of the sporangia of this cone shown in other sections were full of the microspores or the male reproductive organs. Unfortunately the lower part of the cone was absent. It is probable that it had megasporangia with the female reproductive organs, megaspores. Portions of cones which are heterosporous have often been found; a portion of one of these is shown in Plate IX., Fig. 43. On the left hand side of the figure there are two megasporangia, *Meg.*, containing two or three megaspores respectively. On the other side, at *Mic.*, there is a portion of two microsporangia containing microspores, the male reproductive organs; at *L.*, there is the lamina of the sphorophylls with the ligular pit, *lig*. The position of the axis is somewhere about *Ax*. On Plate X., Fig. 44, there is a microsporangia, *Sp.*, containing three megaspores, *meg*. The megaspores in the last two figures are covered with spines, which are split or forked at the ends. This is characteristic of the isolated megaspores met with in association with Bothrodendron twigs and stems.

In association, too, with Bothrodendron there is a very curious seed-like organism (scarcely ever met with, except in blocks which contain Bothrodendron) of a Lycopodiaceous character, which is figured on Plate X., Figs. 46 and 47. Mr. Lomax has found and examined numerous specimens. In 1900 he sent some of the specimens to Miss M. Benson, and she described it as being a new Lycopodiaceous seed-like organ, belonging to *Miadesmia membranaces*, a genus of fossil plants discovered in 1894 by Dr. B. Bertrand, of the University of Lille, France, in the calcareous nodules from the English coal-measures. Some of the specimens of the

seeds found are exceedingly well preserved. The body of the seed is made up of a strong and thick pedicel (*ped.*), Fig. 46, which broadens into a lamina or leaf, as shown in the transverse section, Fig. 47. The end of the pedicel is always blunt, as in Fig. 46, and it shows traces of a vascular bundle, or leaf traces. The length of the lamina is considerable, usually about twice its width. About one-third of the length, from the base of the pedicel, there is a hollow cylinder formed, as seen in the cross section, *Cy.*, Fig. 47, and *Cy.*, Fig. 46. On each side of this are the two lobes of the lamina or leaf, *Lf.* Inserted in the hollow cylinder there is a megasporophyll containing the large seed-like organ, *S.* This is contained in an integumented sporangia (that is, an externally protected sporangia), which has, like ordinary seeds, a micropyle, *Mi.*; the integument is attached to the pedicel by a broad base. On the lower side of this there is a ligule fixed between the lower leaf-like lamina and the integument, thus forming a long ligular cavity; this is shown on the cross section, *Lc.*, Figs. 46 and 47. The upper part of the lamina is covered by numerous hair-like protuberances which extend far beyond the front of the seed. In both the sections these are well shown at *H.* These hair-like tentacles may have played an important part in guiding the wind-borne microspore to the micropyle. It is without doubt one of the most interesting seed-like bodies found in the coal-measures. It is undoubtedly of a Lycopodiaceous origin, and in many respects resembles *Bothrodendron minutifolium*. As a rule, they are found associated together. The seeds are borne on a slender spike, or may have been borne in the case of some of the species in the axils of the leaves, such as *Axl.*, in Fig. 45.

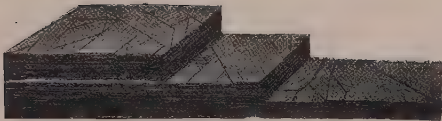


Fig. 48.

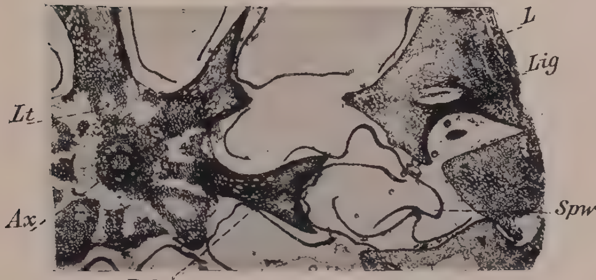


Fig. 42. Mag. 15

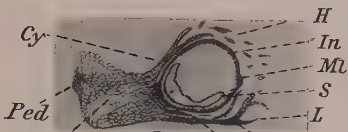
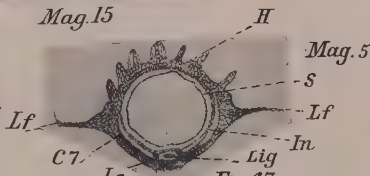


Fig. 46. Mag. 5



Mag. 5 Fig. 47.

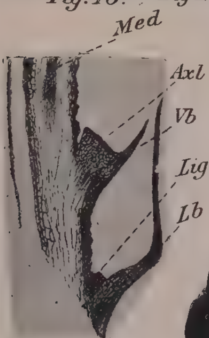


Fig. 45.

Fig. 44. Mag. 10

Photo.] [J. Lomax.

PLATE X.

Lycopodinae: Bothrodendron and Miadesmia.

C. G

It would be easy to transfer the end of the pedicel of Fig. 46 on the top of *Axl.*, Fig. 45. Mr. Lomax has had a number of very young seeds attached to a slender stem in a similar way, which was of a Lycopodiaceous character. It may have been situated, as in the modern Selaginella, at the lower end of a fructiferous spike, as a megasporangia containing only one megaspore, whereas megaspores of Selaginella contain four, each similar to the megasporangia in Figs. 43 and 44. In that case the microsporangia would, as in the modern Lycopods, be at the top of the fruit spike. On Plate IX., Fig. 49, there is a figure of a modern Selaginella, *Selaginella-Emiliana.*

There is also another Lycopodiaceous fruit spike with its seed-like organs, *Lepidocarpon Lomaxi*, which bore numerous seeds with an integument and a micropyle. These cones were like an ordinary *Lepidodostrobus*, and have mostly been found associated with *Lepidodendron Harcourtii*. The assumption is therefore that they belong to the *Lepidodendron Harcourtii.*

The foregoing examples of fructiferous cones are of great interest to the fossil botanist, as they open out a wide field of research and speculation regarding the origin of some of the present seed-bearing plants. It is to be inferred that the whole of the Gymnospermous sub-kingdom was derived from one common stock, and, in a broader sense, from plants which have had a fern-like habit of growth and development.

There are, as shown in *Lyginodendron*, fern-like plants bearing naked seeds of a Cycadean character; from these it seems impossible to doubt that the Cordaiteæ sprang. The Coniferæ are clearly connected through the mediation

of Ginko, or the *Japanese Tree Fern;* and after this the seed-bearing Lycopods become of great interest, more especially when it is known that the vegetative and reproductive organs of such large Lycopodiaceous trees (as *Bothrodendron punctatum* must have been) are not yet fully disclosed. In England several scientists, including Dr. D. H. Scott, F.R.S., Dr. F. W. Oliver, F.R.S., Prof. W. C. Weiss, and others, are endeavouring to trace out the history of these primitive plants. It is to the remains of the prolific vegetation of coal-measure times that they look for the best evidence, which will enable them to more correctly determine the true natural history of plants and trees of every kind; while on the other hand, it is from the Palæo-botanist that the mining student seeks information as to the mode of formation of the seams, information which can only be derived from a close and intimate knowledge of the botany of carboniferous plant remains.

CHAPTER VI.

COALFIELDS OF THE BRITISH ISLES.

Formation of Coalfields.—It is now necessary to consider the manner in which coal comes to be distributed in areas or fields in various parts of the country or throughout the world. Coal does not exist everywhere, nor does it always occur even where it does exist, at the same depths. The three great agents which have caused the earth's crust to be greatly modified are volcanic action, earth and crustal movements, and denudation. All these have assisted, as has been shown in the formation of coal. These same agents have caused vast areas of rocks, including the coal-measures, to be broken up and destroyed, but on the other hand it is owing to their influence that in many parts of the world the rich deposits of fuel have been brought within easy reach of the surface, otherwise they would have been buried under thousands of feet of later formations and be inaccessible. In many cases this result has been brought about by the denudation of the rocks laid down subsequent to the deposition of the carboniferous; in other cases great upheavals and violent foldings have caused the strata comprising the carboniferous series to crop out to the surface from beneath considerable thicknesses of more recent rocks (*see* Fig. 16).

The coal seams of this country are closely related to those of all other coalfields belonging to the carboniferous

formation. The nature of the seams and the rocks associated with them, the mode of formation of the fields, the disturbances to which they have been subjected, the alterations in thicknesses and the variations in qualities, and the species of flora and fauna distinguishing them, are very similar over widely scattered areas and continents. It is probable that in carboniferous times the whole of the British Isles and the Continent of Europe was one vast land area, covered by a luxuriant growth of vegetation which continued for vast ages at a stretch until interrupted by one of the sudden or gradual changes which have already been described. It is a well known feature of the coalfields of the British Isles that the carboniferous series rest conformably on the Old Red Sandstone or Devonian rocks, that is to say, the beds of the one are in the same direction or make the same angle with the horizontal as the beds of the other. Also it is apparent that there has been no great break or interval of time between the

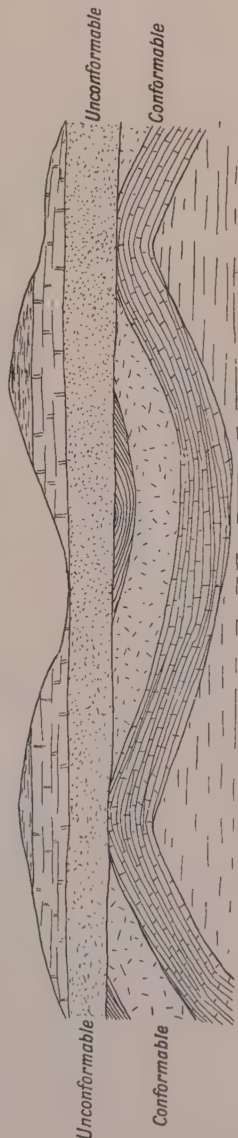


FIG. 14.—Conformable and unconformable strata.

deposition of the one and the laying down of the other; the process has been regular and the life periods have not been greatly interrupted. The carboniferous, however, is not overlain conformably by the Permian or New Red Sandstone formation. The latter rocks lie unconformably, making with the earlier ones a different angle with the horizontal; and between the time when the two formations were laid down there was an important break in the geological record, during which time the carboniferous rocks were undergoing considerable alteration due to great earth movements. These movements — foldings, shrinkings and other disturbances — upset the original stratification. The folding of the rocks was effected first by an east and west force, and subsequently by crushing in an opposite direction. This caused the coal-measures to assume the shape of huge troughs or basins, rising on all sides from a central point, the sides of the basin being composed of sandstone or limestone rocks, the middle afterwards being filled in by strata denuded probably from escarpments of the Devonian and early carboniferous series, and now known as the Permians or New Red Sandstones. The first movement caused the axes of the folds

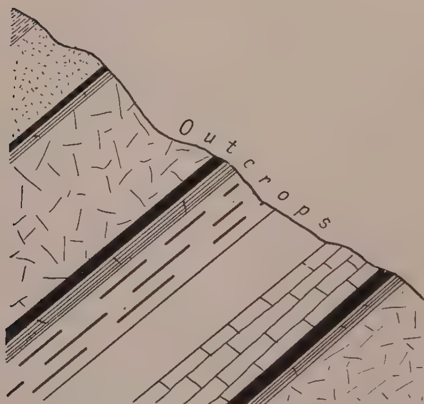


FIG. 15.—Outcrops of coal seams at the surface.

and the strike of the beds to run north and south, with outcrops along the Pennine Chain; the second movement caused the folds to run east and west. It is in this way that so many of the seams of coal crop out at the surface, and even where they do not actually come to the surface, they are, at certain points, within easy reach of it, so that coal may be worked along the anticlines (*see* Fig. 14) before the dip of the measures causes such a depth to be reached as to make further operations impossible.

In Fig. 16 is shown the section of the rocks across the Pennine Chain and the coalfields of Lancashire and Yorkshire. From this it will be seen that the coal-measures, which at one time were continuous over both counties, were separated by denudation after the folding of the beds took place, thus forming separate coal basins on the east and west sides of the chain. In these counties the outcrops are laid bare, but even where they have subsequently been covered up (*see* Fig. 18) by newer formations, there is no doubt that a similar process to that described has been at work, and has not been confined to the basins of this country, but has brought about the extensive and widely scattered coal areas of west

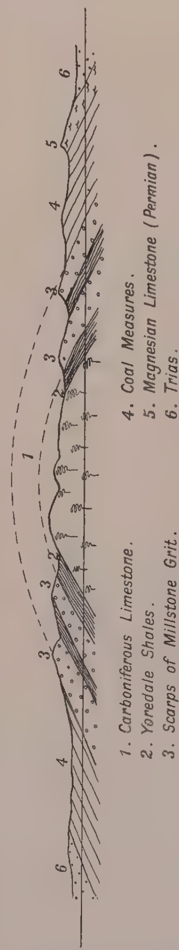


FIG. 16.—Section of strata across part of Lancashire, the Pennine Chain and part of Yorkshire.

and central Europe, of Russia, and in fact of the whole of the coalfields of Asia, North and South America, Africa and the British Colonies.

THE CARBONIFEROUS SYSTEM.—Of all the formations or systems of rocks already referred to, that containing the greatest quantities of Carbonaceous deposits—the carboniferous—is the most interesting. It is true that coal is found in some other formations, but it is in the upper portion of the carboniferous series that the best and most valuable seams of coal are found, viz., in the coal-measures.

In England the coal-measures rest on the Millstone Grit, this again on the Yoredale series, and these pass gradually downwards into the Carboniferous Limestone, thus :—

THE CARBONIFEROUS PERIOD.

	Thickness.
1. Upper or true Coal-Measures	
Upper Coal-Measures Middle ,, ,, Lower ,, ,,	2,000 to 8,000 feet.
2. Millstone Grit	Varies greatly from 400 to 5,000 feet.
3. Yoredales, Carboniferous or Mountain Limestone, and Calciferous Sandstone	800 to 4,000 feet.

THE COALFIELDS OF ENGLAND AND WALES.—There are seven important coal basins in England and Wales, viz. :—*The Newcastle Basin*, *The Cumberland Basin*, *The Lancashire, Cheshire and Flintshire Basin*, *The Yorkshire, Derbyshire*

and Nottinghamshire Basin, The Midland Basin, The South Wales Basin, The South of England Basin.

Area and Available Coal.—The total exposed area of these coalfields is 2,786 square miles. There are in the various fields 190 seams of coal of more than two feet in thickness at a less depth than 4,000 feet. These represent a total thickness of coal of 666 feet, an average of about 3 ft. 6 ins. per seam. According to the final report of the Royal Commission on Coal Supplies (1905) the amount of coal still available in the above areas, excluding all seams of less than two feet in thickness and more than 4,000 feet deep, is 79,467,820,017 tons. But there are also good seams of less than two feet in thickness, and there are many seams occurring at greater depths than 4,000 feet, and these, together with numerous seams which exist in concealed or unproved coalfields, are estimated to contain no less than 66,169,282,130 tons. This, with the above-named quantity, amounts to 145,637,102,147 tons. The present annual output of coal is about 230,000,000 tons, so that at the present rate of extraction the coal resources of this country should last for 633 years.

In many cases the whole of the basin areas are not exposed, nor at the present time are the whole of the seams explored, as newer and comparatively little-known formations cover up the coal-measures. This is the case with the eastern extension of the Yorkshire, Derbyshire, and Nottinghamshire field, the southern extension of the Lancashire field, and with large areas in the Midlands and South of England, while on the other hand the western limit of the Cumberland field, the eastern boundary of the Newcastle field, and a large area of the South Wales field

are under the sea. The extent and boundaries of these fields have not yet been thoroughly proved, but there is little doubt that the unproved areas are very large, and that the Royal Commission's estimate of 40,000,000,000 tons of coal available therein is not less than they actually contain.

Some difficulty may be experienced in working those seams of coal found at great depths, for it must be evident that the winding of large quantities of coal from great depths, and the distribution of adequate volumes of fresh air through remote and extensive workings have their economical limits, and to these drawbacks must be added the difficulties experienced owing to the increase in the temperature of the strata.

The Newcastle Basin.—The proved portion of this area covers the eastern side of the counties of Northumberland and Durham. Along the coast it extends a distance of about sixty miles from the River Coquet in the north to Staindrop (on the north of the Tees) in the south (*see* Map, Fig. 17). Inland it stretches to Wolsingham, a distance of over twenty miles. It is bounded on the east by the North Sea and the Magnesian Limestone; on the south by the Magnesian Limestone and Millstone Grit; on the west by the Millstone Grit; and runs out to an apex in the north. The total exposed area is 540 square miles. There are 20 seams of coal of not less than 2 feet, having a total of 46 feet of workable coal and an estimated quantity of 11,532,957,384 tons.

The Cumberland Basin.—This coal area covers the northern and western portion of Cumberland. It stretches from Maryport in the north to St. Bees in the south, a

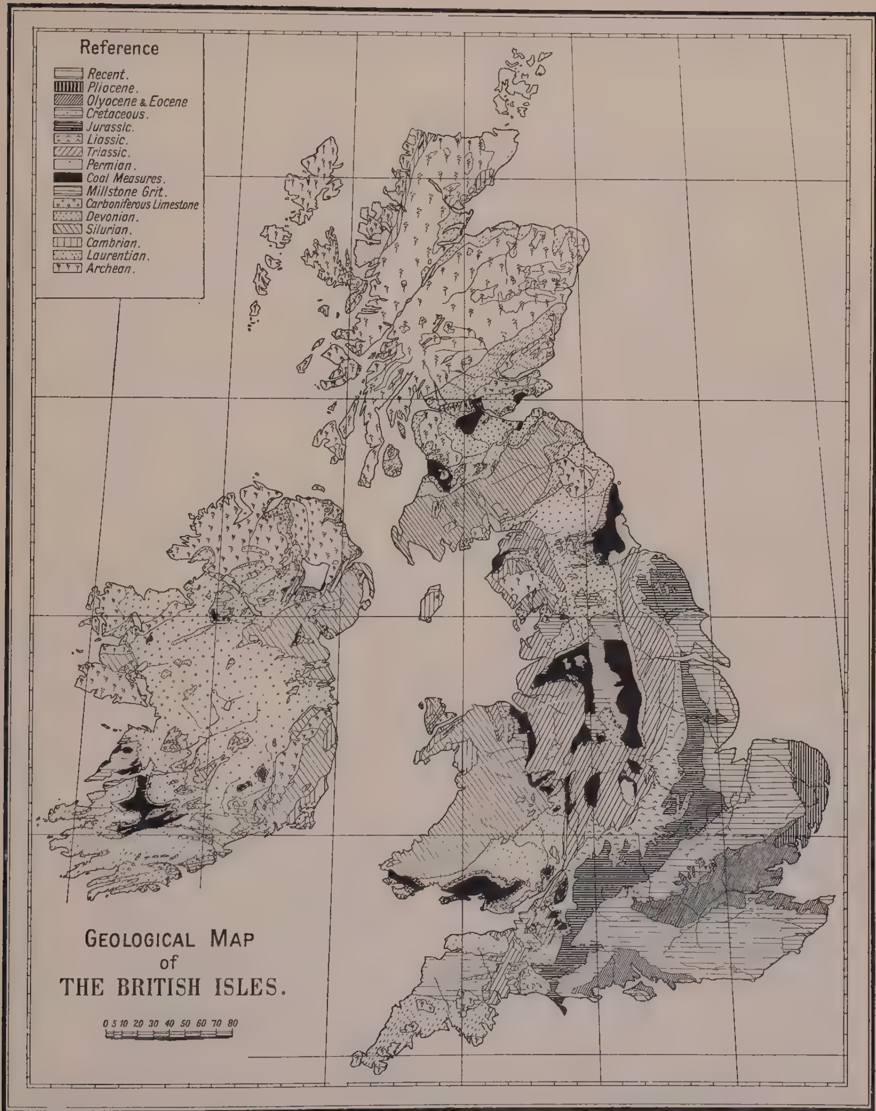

Reference
Recent.
Pliocene.
Olyocene & Eocene
Cretaceous.
Jurassic.
Liassic.
Triassic.
Permian.
Coal Measures.
Millstone Grit.
Carboniferous Limestone
Devonian.
Silurian.
Cambrian.
Laurentian.
Archean.
GEOLOGICAL MAP
of
THE BRITISH ISLES.
0 5 10 20 30 40 50 60 70 80

FIG. 17.

distance of twenty miles. At Maryport the visible field bends round to the east a distance of fourteen or fifteen miles to near Westward, forming a narrow strip about two miles wide, between the New Red Sandstone and the Carboniferous Limestone rocks. The coalfield is bounded on the west by the Irish Sea, on the east by the Carboniferous Limestone from Egremont in the south to Westward in the north, with thin strips of Millstone Grit at Eaglesfield and Tallentine; in the north by the New Red Sandstone; in the south by the Permian, New Red Sandstone, and Carboniferous Limestone. The total area is sixty-three square miles, but there is a large extent of coalfield beneath the Irish Sea. There are seven workable seams with a total thickness of 35 feet and an estimated available quantity of 1,980,556,809 tons. The undersea area which lies beyond five miles and within twelve miles of high water mark is estimated by Sir Lindsay Wood to contain 854,000,000 tons.

The Lancashire, Cheshire and Flintshire Basin.—This coalfield consists of two detached areas, the larger one covering almost the whole of South Lancashire and a portion of East Cheshire, the smaller one covering the whole of the eastern half of the county of Flint. It is bounded on the north by the Millstone Grit, and on the east by the great anticline of Millstone Grit forming the Pennine Chain; on the west and south-west of the Lancashire area, the coal-measures dip below the New Red Sandstone rocks, appearing again on the opposite side of the river Dee, outcropping in Flintshire, a few miles beyond the river. The greater portion of Cheshire, therefore, consists of Permian and Triassic formations, deposited in a coal-measure basin, the sides of which outcrop on the

north, south-west, and west. Whether the basin is an uninterrupted one or not is so far unproved; it is generally considered that a concealed ridge of lower rocks, running along the valley of the Mersey, interrupts the continuity of the basin, and this causes the formation of two smaller ones.

The whole exposed field covers an area of 650 square miles, and, including the concealed area, probably contains 1,500 square miles of productive coal-measures. In all there are 24 seams of coal, with a total thickness of workable coal of 97 feet. The total estimated quantity of coal remaining unworked in this basin is 6,031,392,367 tons.

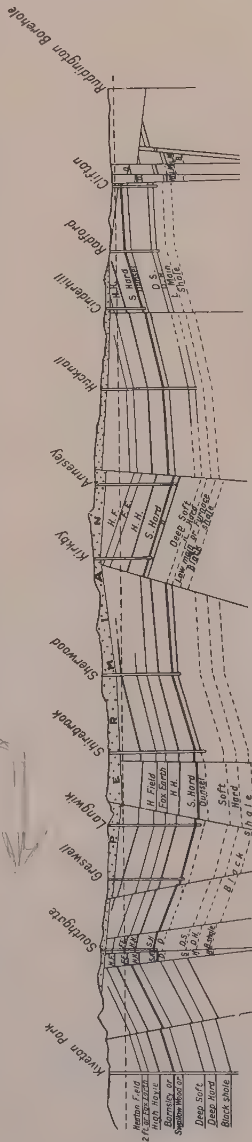


FIG. 18.—Section across a portion of the Yorkshire, Derbyshire and Nottinghamshire coalfield.

The Yorkshire, Derbyshire and Nottinghamshire Basin.—This is the most extensive coalfield in England, stretching over a large portion of the counties of Yorkshire, Derbyshire, and Nottinghamshire. It stretches from Leeds and Bradford in the north to Stapleford and Nottingham in the south, a distance of over seventy

miles. It is bounded on the north and west by the Millstone Grit and Yoredale beds; on the east by the Permians; and in the south by the Triassic. A large area of coal is now being worked beyond the eastern boundary of the exposed field, in the neighbourhood of Worksop, Mansfield and Nottingham, and extending right into Lincolnshire, where the same valuable seams have been found below the newer formations. The coalfield is 810 square miles in extent exclusive of the eastern extension, which probably covers an area of nearly 1,000 square miles. There are 15 seams of coal with 46 feet of total thickness. The estimated available quantity of coal in the proved area is 16,498,731,495 tons. The resources of the concealed and unproved coalfield are estimated at 23,000,000,000 tons.

The Midland Basin.—This includes the coalfields of Denbighshire, North and South Staffordshire, Warwickshire, Leicestershire and Shropshire. The fields consist of a number of detached areas of exposed coal-measures with other portions of productive measures overlain by newer formations. The boundaries of the various fields are not in each case the same. The *Denbigh field* is bounded on the north, west and south by the Millstone Grit, on the north-east by the Triassic, on the east by the Permians. The *North Staffordshire field* is bounded on the west by the New Red Sandstone, on the east by the Millstone Grit, on the south the measures dip beneath the Permians, while on the north the field runs out to an apex. The *South Staffordshire field* including the *Worcestershire* area is bounded by faults on both the east and west sides which bring the New Red Sandstone rocks into juxtaposition with the coal-measures. The *Warwickshire field* is bounded on

the north, west and north-east by the Triassic rocks, on the east there is a long strip of Cambrian rocks stretching from Atherstone to Bedworth, where the Triassic rocks again appear; on the south the coal-measures pass below a large tract of Permians. The *Leicestershire field* is bounded on the north partly by the Triassic and partly by the Millstone Grit and the Carboniferous Limestone; on the west, south and east by the Triassic. The *Shropshire fields*. There are four detached fields in Shropshire, one in the neighbourhood of *Oswestry*, another immediately south and east of *Shrewsbury*, another seven miles to the *south of Shrewsbury*, and a fourth, called the *Coalbrookdale field*, stretching down the west side of the county from Lilleshall to Bewdley. The latter is the most important coal producing area. It is bounded on the north by the Triassic, on the east by the Permians, on the west by the Millstone Grit, Silurian and Devonian, on the south by the Devonian.

The *North Staffordshire* measures dip beneath the Permians on the southern boundary, and the coal-measures of the Warwickshire field also pass below the Permians in the south. The latter stretch from near Atherstone to midway between Kenilworth and Warwick, covering an area of 130 square miles. Here, under the newer measures, valuable seams of coal are found at no greater depth than 2,500 feet. Large coal areas also lie concealed between South Staffordshire, Coalbrookdale and the Forest of Wyre and between South Staffordshire, Warwickshire and Leicestershire. The area of the whole of the visible fields in the Midland basin is 690 square miles. There are 51 seams of coal, including the famous *Thick* or *Ten Yards* seam of South Staffordshire, the whole of the seams having

a total thickness of 250 feet. The estimated quantity of available coal in the exposed areas is 11,935,568,586 tons, and it is calculated that the resources of the concealed and unproved coalfields of the whole basin will be equal to nearly 13,000,000,000 tons.

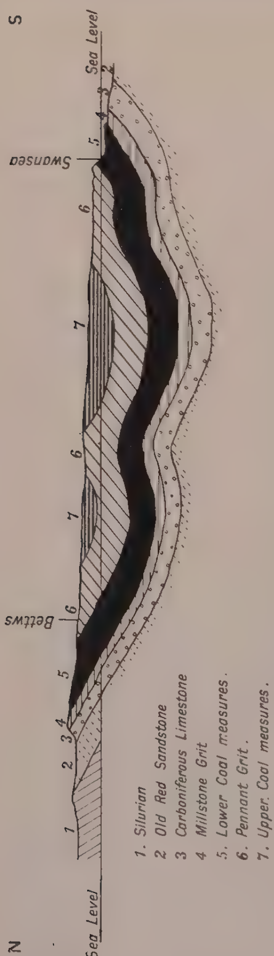


FIG. 19.—Section across the South Wales coalfield.

The South Wales Basin.—This is the most interesting coal basin in Great Britain, not only on account of the enormous quantity of coal which it contains, but because of the excellent quality and great value of the majority of the seams. It stretches across the whole of South Wales from Pontypool in the east to St. Bride's Bay in the west, a distance (exclusive of the under-sea coal in Carmarthen Bay) of ninety-two miles. The average breadth is sixteen miles. It lies in the form of a basin in a depression of Devonian or Old Red Sandstone rocks, by which it is surrounded on all sides with narrow strips of Millstone Grit and Carboniferous Limestone lying between the outcrops of the coal-measures and the Devonian. The general dip of the

measures is towards the south (see Fig. 19), and were it not for the existence of a remarkable anticlinal axis stretching in an easterly and westerly direction across the coalfield the coal seams, especially near the southern boundary, would quickly become too deep to be worked. Owing to this anticline, however, the coal-measures are brought within easy reach of the surface, thus enormously increasing the area of available coal. There are also large quantities of coal, especially of *Anthracite* in the unproved measures occurring beneath the sea in St. Brides' Bay and part of Carmarthen Bay, which will be worked within a comparatively short time. The total area of the visible field is 920 square miles. There are 25 seams of coal with a total thickness of 84 feet. The total estimated quantity of coal remaining to be worked is 27,031,798,830 tons, and in the concealed areas already referred to a further quantity of 383,024,000 tons.

The Southern Coal Basin.—This includes the coalfields of Bristol and Somersetshire, the Forest of Dean and Kent. *The Bristol and Somersetshire field* is situated partly in the south of Gloucestershire and partly in the north of Somersetshire. Over a great part of its area the coal-measures are covered by newer formations, viz., the Lias and the Upper Triassic beds, which lie horizontally upon them. The visible field is bounded on all sides except the east by one or both of these rocks. On the east side the measures pass beyond the Cotswold Hills, beneath the Oolitic rocks. Their extent in this direction is unknown, but it is most probable that they continue, with slight alteration, right across southern England into Kent. *The Forest of Dean Coalfield* is situated in Gloucestershire on the north side of the mouth

of the River Severn, and is one of the most interesting of the British coal areas. It is in the form of a complete basin, resting on the Carboniferous Limestone, the latter measures rising up all round the outcrop of the coal-measures. The Carboniferous Limestone rocks therefore form a huge basin, encompassing the coal-measures within, so that the latter dip toward the centre from all sides, although not equally nor always at a uniform rate. *The Kent Coalfield.* The coal-measures do not occur at the surface over any portion of this field, but in the neighbourhood of Dover, at a depth of 1,204 feet, the coal-measures are found below the Jurassic and Cretaceous rocks. Very little is known of the extent and thicknesses of the coal seams. The measures no doubt extend westward in the form of a trough towards the borders of the Bristol and Somersetshire field, and eastward under the English Channel to the coalfield of Northern France and Belgium. The width of the field from north to south is about four or five miles.

The combined area of the exposed fields comprising the Southern Coal Basin is about 184 square miles, and, including the unexposed but productive areas, about 400 square miles. There are 48 seams of coal having a total thickness of 108 feet. The quantity of available coal is estimated at 4,456,834,546 tons. There is not at the present time sufficient data to estimate the probable amount of coal in the unproved areas of Somersetshire and Kent.

The Coalfields of Scotland.—The coalfields of Scotland are found in the great valley which stretches from the mouth of the Clyde on the west to the Firth of Forth on the east, and are closely associated with the courses of those

two rivers. They occupy portions of the counties of Fife, Stirling, Dumbarton, Renfrew, Lanark, Ayrshire, Dumfriesshire, Haddingtonshire, and Edinburghshire. Great upheavals of older rocks, such as the Calciferous Sandstone series, and volcanic rocks, have had the effect of separating one area from another, and these may be divided into the following basins:—

Eastern Basin.—This includes the coalfields of Midlothian, Haddingtonshire, and Fifeshire, and the coal beneath the Forth.

Central Basin.—This includes the Clyde and Clackmannan fields, with the detached field of Lesmahagow.

Western Basin.—This includes the Ayrshire and Dumfriesshire fields.

Coal is worked not only in the coal-measures proper, but in the beds akin to the Yoredales of Derbyshire and Lancashire, and the Carboniferous Limestone. In the case of each field, the Carboniferous Limestone rocks almost completely surround the coal-measures, with eruptions of volcanic rocks of basalt and greenstone at various points, notably in the centre of the Ayrshire field and at Hamilton, Glasgow, and Airdrie. The northern boundary of the main coalfield, viz., in Clackmannan, is against the Andesites, a volcanic series similar to that of Borrowdale and the Cheviot Hills. The area of the combined fields is about 568 square miles. The total estimated quantity of coal remaining unworked in the proved areas is 15,089,333,985 tons.

The Coalfields of Ireland.—Up to the present time very few of the seams of coal of which Ireland is possessed have been worked to any great extent, and consequently very little is known of the geology or the resources of the

coal-measures. There is no doubt, however, that a large amount of coal exists in Ireland, and though on the whole its quality is not so good as that of the United Kingdom, it is of a workable quality and thickness over certain areas of the country.

The carboniferous formation in Ireland may be divided into two parts, the Lower Carboniferous and the Upper Carboniferous, while the coalfields may be divided into two groups—the *Northern Group*, in the provinces of Ulster and Connaught, which includes the coalfields of Ballycastle, Tyrone, Leitrim, Fermanagh, and Cavan, and contains seams of bituminous coal; and a *Southern Group*, in the provinces of Leinster and Munster, which includes the coalfield lying around Castlecomer and Killenaule, in the counties of Queen's County, Kilkenny, Carlow, and Tipperary.

CHAPTER VII.

FOREIGN COALFIELDS.

Coalfields of the United States of America.

The amount of coal now raised in the United States is greater than that of any other country in the world. From the very beginning of coal mining until 1899 the production of this important mineral had been greater in the British Isles than in any other country. In the latter year the United States, which had been gradually but surely increasing its total output, passed the British total, and since that time has exceeded by more than 100,000,000 tons the present British output. This is because the vast fuel supplies of America have recently been thoroughly opened out, and greatly improved methods of mining them have been adopted.

One-half of the coal is produced in Pennsylvania, where valuable seams of *Anthracite* are found, as well as many rich beds of bituminous and semi-bituminous coals. The seams are in most cases of carboniferous age, the coal-measures resting upon the Carboniferous Limestone with the Millstone Grit in some cases intervening. In Virginia and North Carolina coal is found in the Triassic rocks.

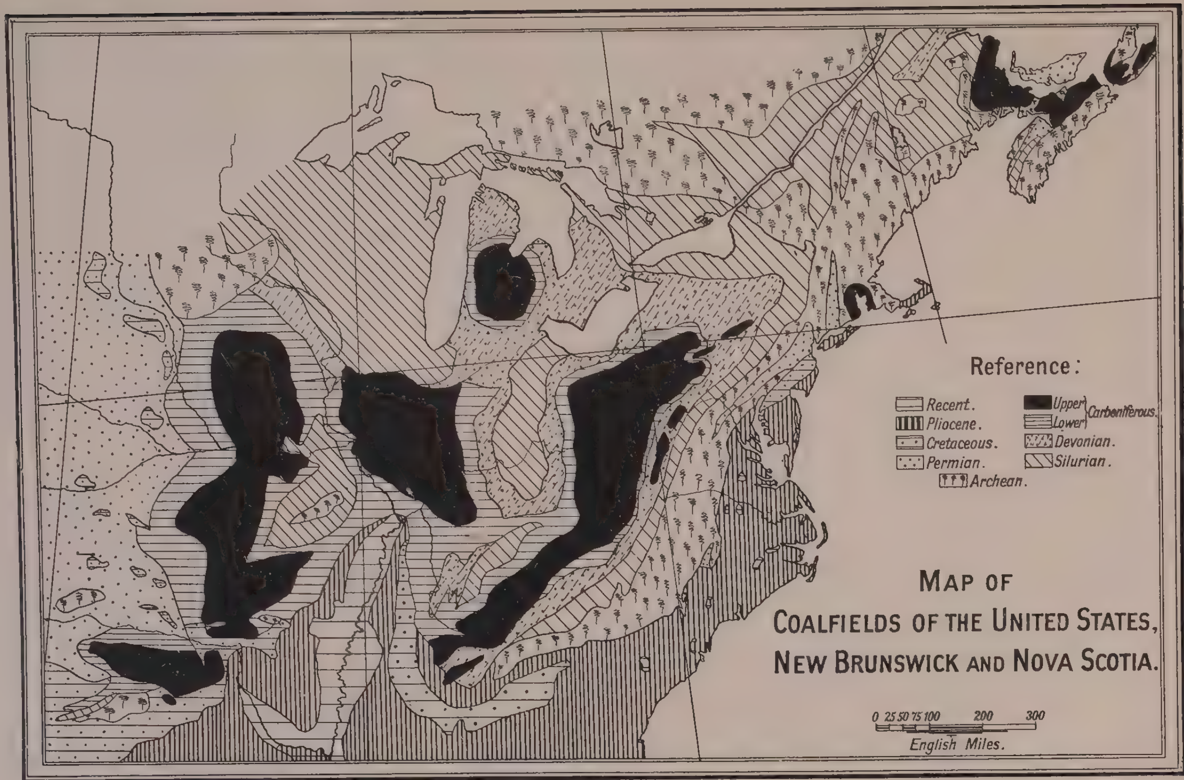
The coalfields have a superficial area of 229,000 square miles, of which one-sixth contains workable seams. The

fields are situated in positions easily accessible both to home markets and important sea ports, while the deposits are thick and in many cases near the surface, so that they can be worked easily and cheaply. The majority of the seams are valuable, including bituminous, semi-bituminous, and anthracite. Lignite is also met with in large quantities. It is calculated that lignite-bearing formations of Cretaceous age in Montana, Dakota, and Wyoming, cover an area of 56,500 square miles. In Alabama, Mississippi, Louisiana, Arkansas, and Texas, an equally great extent of Tertiary lignite-bearing rocks is found.

Coal of Upper Cretaceous and Eocene age is also found in Alaska, where the seams vary in thickness from about 2 feet to 5 feet, and in quality from lignite to semi-bituminous.

The following table is taken from the special reports on the coal resources of the United States contained in the Report of the Geological Survey of that country, and published in 1902:—

Coalfield.	Area of Coal-bearing formations. Square miles.	Per cent. of total production.
Anthracite Field:		
Colorado, New Mexico	—	0·04
Pennsylvania	484	21·25
Atlantic Coast (Triassic):		
Virginia	270	—
North Carolina	800	—
Total	1,070	0·02



Reference:
Recent.
Pliocene.
Cretaceous.
Permian.
Archean.
Upper
Lower
Carboniferous.
Devonian.
Silurian.
MAP OF
COALFIELDS OF THE UNITED STATES,
NEW BRUNSWICK AND NOVA SCOTIA.
0 25 50 75 100 200 300
English Miles.

FIG. 20.

Coalfield.	Area of Coal-bearing formations. Square miles.	Per cent. of total production.
Northern Appalachian:		
Pennsylvania	15,800	29·58
Ohio	12,000	7·03
Maryland	510	1·49
Virginia	1,850	0·87
West Virginia	17,280	8·39
Kentucky (E.)	10,300	0·82
Total	57,740	—
Southern Appalachian:		
Tennessee	4,400	1·38
Georgia	167	0·12
Alabama	8,500	3·11
Total	13,067	—
Northern Interior:		
Michigan	11,300	0·31
Eastern Interior:		
Indiana	9,300	2·40
Illinois	42,900	9·55
Kentucky (W.)	5,800	1·15
Total	58,000	—
Western Interior:		
Iowa	20 000	1·93
Missouri	23,000	1·31
Nebraska	3,200	—
Kansas	20,000	1·65
Total	66,200	—

Coalfield.	Area of Coal-bearing formations. Square miles.	Per cent. of total production.
South-Western:		
Indian Territory	14,848	0·71
Arkansas	1,728	0·54
Texas	11,300	0·36
Total	27,876	—
Rocky Mountains:		
South Dakota	120	0·05
Montana	13,000	0·62
Idaho	—	—
Wyoming	7,500	1·49
Utah	2,000	0·42
Colorado	18,100	1·92
New Mexico	2,890	0·47
Total	43,610	—
Pacific Coast:		
Washington	450	0·92
Oregon	320	0·02
California	280	0·07
Total	1,050	—

The total output of coal in 1905 was 352,694,000 tons. It will be easily understood that with such vast and widely-scattered coal areas it is impossible to give a reliable estimate of America's coal resources. A Commission, appointed by the Government of Pennsylvania, reported in 1893 that the anthracite beds alone of that State covered an area of 484 square miles and contained 19,500,000 tons of coal, and it is not likely that the anthracite beds represent more than 0·05 per cent. of the whole area of 229,000 square miles of coalfields.

Coalfields of Europe.

Germany.—Germany produces more coal annually than any other European state, except Great Britain. The three principal coal-mining districts are as follows:—

1. The Rhur, or Lower Rhine and Westphalia Basin.
2. The Upper Silesian Basin.
3. The Saarbrucken Coal Basin.

The Rhur Coalfield is the largest and most important of the above coal areas. It covers an area of more than 1,080 square miles, and shafts are sunk to a very great depth in many parts of the field. The coal seams are generally of carboniferous age, not only in this area, but in those of Upper Silesia and Saarbrucken; there are, however, fairly extensive workings in the Cretaceous rocks of Hanover. The seams are numerous in the Rhur field, aggregating nearly 60 yards of workable coal. They are of bituminous and semi-bituminous quality, but as a rule, owing to the fact that the measures are in many cases greatly disturbed and have bands of dirt and stone instratified with the coal, the quality is inferior to British coal. This applies to most of the coal-producing districts.

The Coalfields of Upper Silesia are very extensive and are continued into Austria and Russia. The seams are fairly numerous and have an average thickness of 10 to 18 feet. The seams are more regular than those of the other fields, though not of better quality. In Saxony important coal-basins are found, though of limited extent at Zwickau and Lugau. Here the seams are over 30 feet thick in places.

The Saarbrucken Coalfield, though not so large in area,


Geological Map of
Northern France
with the Coalfields of
Belgium and Prussia.
10 0 10 20 30 40 50
Reference.
Recent.
Pliocene.
Cretaceous.
Jurassic.
Liassic.
Triassic.
Permian.
Upper Carbon.
Lower Carbon.
Devonian.
Silurian.
Archean.

Fig. 21.

possesses several valuable seams, and on account of the improved methods of mining adopted in the various seams, is probably in advance of other districts. The field covers an area of about 1,000 square miles. There are 77 workable seams with an aggregate thickness of 260 feet.

Near to the Ruhr coalfield, are the two coal basins of *Inde* and *Wurm*. The former has in the past been extensively worked, but is now nearly exhausted. The Wurm area is considerably disturbed by faults. There are 35 workable seams with an aggregate thickness of 82 feet.

The total coal output of the whole of the German empire, in 1905, was 173,664,000 tons. The estimated amount of available coal is as follows :—

	Millions of Tons.
Ruhr Field	45,000
Silesia	50,000
Saarbrucken	45,400

Brown Coal.—Germany is almost as rich in brown coal or *Lignite* as in true coal, and during recent years the improved methods of mining and of preparing this product for the market have caused great interest to be taken in the brown coal industry of Germany. Deposits are found in more or less abundance over nearly the whole of North Germany. The beds are generally found near the surface and in many cases are worked in open quarries.

The chief lignite fields are those of Lower Silesia, Saxony and Posen, Brunswick, Thuringia, and Hesse; while coal which appears to be a hard variety of lignite is found at Cassel and Cologne. The average thickness of the lignite seams is about 100 feet.

The production of brown coal in Germany in 1905 was 51,655,000 tons. The amount still available in the empire is estimated at 5,000,000,000 tons, an amount which is equal in heating value to 3,000,000,000 tons of true coal.

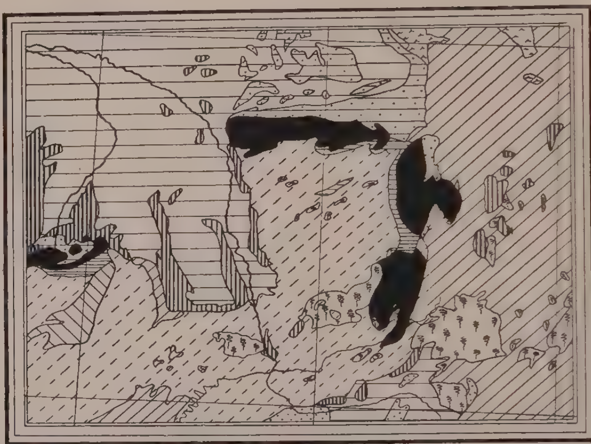
Austria-Hungary.—The chief Austrian coal deposits are those of Pilsen, Kladno-Schlan-Rakonitz, Schatzlar-Schwadowitz, Ostrau-Karwin and Jaworzno. These are all situated along a line running from the Bavarian frontier in the west to the Russian frontier in the east, while somewhat to the south of this line is the Rossitz field in Moravia.

The coal seams of Austria are of carboniferous age. The main coalfield is that of Ostrau-Karwin. This is an extension of the upper Silesian field of Germany, and contains over 300 seams with a total thickness of 1,500 feet, of which about one-third is workable. The seams are chiefly bituminous.

Brown Coal is worked on a large scale in Bohemia, and in other parts, the lignite mining industry having now attained almost greater importance than true coal mining. It is of Jurassic age. The largest field is that of Erzgebirge. The deposits here are quite flat and forty to fifty feet thick.

Hungary is not so rich in carboniferous coal as in lignite. Deposits of the former occur at Resicza-Szekul, but there are a few seams and these are of small extent. Liassic coal is worked in several districts, but the total output of true coal from Hungary is relatively small, viz.: about 1,200,000 tons.

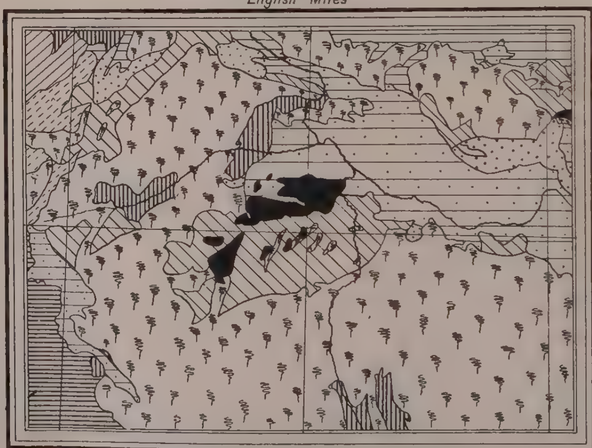
Lignite is worked largely. It is of Tertiary age and is met with in the Carpathians, in the vicinity of Salgo-Tarjan, and in Transylvania in the Zsill valley, the latter being the most important.



THE COALFIELDS OF WESTPHALIA.

0 5 10 20 30 40 50 100

English Miles



THE COALFIELDS OF BOHEMIA.

Reference.

Recent.
Pliocene.
Cretaceous.
Jurassic.
Liassic.
Triassic.
Permian.
Upper Carboniferous.
Lower Carboniferous.
Devonian.
Silurian.
Archean.

FIG. 22.

The output of true coal from the whole of Austria-Hungary in 1905 was 40,725,000, almost the whole of which was raised in Austria.

The output of lignite in 1905 was 27,757,000 tons, of which 5,430,000 tons was raised in Hungary.

Nasse estimates the total coal resources of Austria-Hungary to be about 17,000,000,000 tons.

France.—Coal is found in three main districts in France, each of them possessing distinct geological features. The most important coal-producing area is that of the *Nord and Pas de Calais*, which extends from the Belgian frontier in the east to near Boulogne-sur-Mer in the west, and forms a continuation of the trough stretching from Dover to Calais beneath the sea, and connecting this to the Belgian coalfields in the east. The coalfield is, to a large extent, concealed under newer formations of Cretaceous and Tertiary age, and the trough is frequently dissevered, as at Liège and Mons, being thrown into elongated basins by the elevation of the lower carboniferous rocks. Large numbers of seams occur, but they are irregular, and as a rule, thin. Deep boreholes have been put down along the southern boundaries of the field which prove that there is a considerable extension of this field to the south. The Lens and Courrieries and Auzin Collieries are situated in this area. These are amongst the largest collieries in the world, the former alone, in 1905, having a total production of three and a half million tons.

In *Central France* coal basins are found at Le Creusot and Blanzy, and Loire. The Le Creusot and Blanzy district is remarkable for the fact that it possesses a single seam of great thickness, viz., 80 to 150 feet.

The Loire basin is the richest and most extensive coal area and contains the coalfields of St. Etienne, Rive-de-Gier and Commentry. It is situated between the Loire and the Rhone, extending across the latter river into the department of Isère. At St. Etienne there are 18 seams with an aggregate thickness of 115 feet; at Rive-de-Gier there are 3 seams with an average thickness of 30 to 33 feet.

The Commentry field is of great geological interest. This is a comparatively small coal basin which lies in a depression in the Archæan rocks (granite and gneiss). M. Fayol, who closely studied this field, came to the conclusion that, owing to certain movements of the earth's crust at the commencement of, or during the carboniferous period, an inland lake about six miles long, three miles wide and 2,500 feet deep had been formed. On the north of this area the land rose rapidly, forming a range of mountains, and from this high ground two rapid rivers and several smaller streams poured their contents into the lake (*see* p. 19). In this way, the lake was gradually filled up, deltas were formed and at certain periods vast quantities of vegetable matter were brought in by the rivers. These remains, like the sand and the mud, floated out into smooth water, sank to the bottom, and formed sloping sides of new deposits upon the already existing sides of the basin. Since that time very slight geological changes have taken place, and the basin is now found practically the same as when first deposited. Consequently a very regular seam of great thickness (65 feet) is found in this field, which extends for a distance of ten miles.

In Southern France the coal-measures occur at the surface in the districts of Alais, Aveyron, and the Rhone,

lying in places as crystalline schists, and on the other side below Liassic strata.

The total quantity of coal raised in France in 1905 was 36,048,000 tons, and it is estimated by A. de Lapparent ("Question du charbon de terre," Paris, 1890) that the available quantity in the whole of France is 17,000,000,000 tons.

A quantity of *Brown Coal* is also worked, the output in 1905 being, however, less than 1,000,000 tons.

BELGIUM.—The coal-measures of this country stretch along an east and west trough from Aix-la-Chapelle, by Liège and Namur, to the North of France coalfield. The field crops out near Namur and dips both towards the west and the east, forming the *Hainault Basin* in the first case and the *Liège Basin* in the second, and covering in all an area of 520 square miles. The seams on the whole are thin, the average of seams worked being 2 feet 2 inches. Like those of France the coal seams are of carboniferous age, and in some parts are concealed below Cretaceous rocks.

During the last few years a new coal area has been proved at Limburg and at other places in Northern Belgium, named the *Campine Coalfield*, which is of great extent. The coal-measures are met with at a depth of 1,705 feet from the surface, concealed below Cretaceous and Tertiary rocks. The field is a prolongation of those of Liège, Dutch Limburg, and the Wurm basin. It covers an area of 400 square miles, and is estimated to contain 500,000,000 tons.

The total quantity of coal raised in Belgium in 1905 was 21,844,000 tons, and the estimated available amount of

Belgian coal was given by Nasse in 1895 at 16,000,000,000 tons.

Russia.—Russia does not possess rich or even extensive deposits of coal in comparison to the great area of the country. The coalfields are not numerous, and the seams are thin and poor in quality. The coalfields may be divided into the *Donetz field* in Southern Russia, the *Central Russia field*, the basin of *Kousnetsk* in the Altai and the Ural Range, and the *Poland Basin*. The coal-measures belong to the carboniferous age.

The Donetz Basin is the most important. The carboniferous deposits cover an area which extends over a length of 233 miles from east to west, with a maximum breadth of 100 miles. They are in part overlain by Permian rocks, but crop out at the surface over an area of 7,720 square miles. The seams as a rule are thin, and number about 200. The best seams are found in the Middle group and consist of bituminous, semi-bituminous, and anthracite.

The Central or Moscow Coalfield covers an area of 9,000 square miles, but up to the present time only the outcrops of the seams have been worked. The coal is not of good quality, resembling lignite from the Tertiary rocks, though some classes are used largely for gas-making.

The Poland Basin, though small, is extremely productive and of great value. Like the other Russian fields it belongs to the carboniferous period. There are three main seams, one of which is 16 yards thick.

In Siberia coal is found chiefly in the Altai and the Ural Range, at Kousnetsk, and in the Kirghiz Steepe, the Caucasus, Turkestan, Pavlodar, and in the island of Saghalien.

The total quantity of coal raised in Russia in 1905 was 17,120,000 tons. It is difficult to estimate the total quantity of coal still available, but it is certainly not less than 20,000,000,000 tons.

Spain.—Valuable coal deposits, covering a total area of 3,500 square miles, are found in Spain, but up to the present the amount of coal produced has been small, amounting in 1905 to no more than 3,200,000 tons.

Deposits of carboniferous age are found covering a wide area in Asturias; Leon and Palencia in the north; in Cordova in Central Spain; in Gerona and Lerida on the slopes of the Pyrenees; and in Seville in the south. The coal is of good semi-bituminous character, and of considerable thickness; there are 50 workable seams, varying in thickness from 18 inches to 6 feet in the Asturias province alone. In the Province of Tervel is a valuable field of *Lignite*, and seams of anthracite are found in the province of Cordova.

Greece.—Very little coal of good quality is found in Greece, although good seams of lignite are met with in Coumi, Oropos, and Aliverion, the mines of the former province being the chief ones worked. Lignite deposits are also found at Magalopolis, Patras, Egion, Attica, Phtiotis, Euboea, Allonisos, and in Thessaly.

Portugal.—The coal production of Portugal in 1905 was about 20,000 tons. The coal areas are of very limited extent. Anthracite coal is found in the Douro district and bituminous coal in the Jurassic rocks of Cape Mondego.

Servia.—Coal is found in the Tenioh Valley, near Tschuka, of carboniferous age, and at Dobra and other

places on the Danube in the Liassic formation. Lignite is also found, many of the beds being of fair thickness.

Roumania.—Roumania raises about 100,000 tons of coal annually. This is lignite, of poor quality, found in the Pliocene Rocks. The beds are generally very thick, and are widely distributed over the kingdom.

Bulgaria.—The coal output of Bulgaria in 1905 was 130,000 tons. The coal is chiefly lignite, of Eocene age.

Sweden.—Coal is found in Sweden in the Jurassic rocks. These occur in Scania in the southern portion of the country, and extend over a distance of 620 square miles. The seams are of fair thickness, but are not worked on a large scale, the total coal production of 1905 being about 250,000 tons.

Switzerland.—A small amount of coal of an anthracitous character, and belonging probably to the carboniferous age, occurs amongst the Western Alps, stretching through Savoy into Dauphiné.

Italy.—Italy is not a coal-producing country, raising less than half a million tons per annum, though deposits of bituminous coal are found in the province of Udine, and deposits of anthracite in Piedmont. Lignite is produced on a small scale in the provinces of Vicenza, Verona, Berganio, and in the islands of Sardinia. The former coals are of carboniferous age, while the lignite probably belongs to the Lias formation.

Denmark.—In the island of Bornholm a small amount of bituminous coal is found, and lignite occurs in Jutland and the islands, but the production both of bituminous coal and lignite is very small and not sufficient even for local requirements.

Holland.—The coalfields of Holland are chiefly interesting from the fact that it was at Kerkrade, near Haarlem, that coal was mined by the monks of Klosterrath Abbey as early as 1113. A coalfield has recently been proved which forms a continuation of the Wurm basin into Limburg. Like the coal of Belgium and France, that of Holland is found in the Secondary rocks. The production of coal in 1905 was less than 10,000 tons.

Coalfields of the British Colonies.

Canada.—The coalfields which have been most largely developed in Canada are found on the Atlantic coast on the one side—Nova Scotia, New Brunswick and Cape Breton—and the Pacific coast on the other—British Columbia, Vancouver Island and Queen Charlotte Islands. In Manitoba and the North-West Provinces large deposits of coal are found, and these will, no doubt, be largely developed in the future.

The areas on the *Atlantic* side are very extensive, covering in Nova Scotia alone no less than 4,000 square miles. The seams are of true carboniferous age, and are generally very thick and of good quality, those of Nova Scotia being steam coals equal to good British steam coals.

On the *Pacific* side the seams are of cretaceous age and are generally bituminous. Anthracite and bituminous seams are found in Queen Charlotte Islands.

In the *Crow's Nest Field*, thick seams of bituminous and semi-bituminous coal exist. In the interior of Canada little coal is found between the Atlantic and the Western Prairies, but great quantities of good lignite are found in the latter

district. The seams improve greatly in quality towards the Rocky Mountains, yielding good bituminous coal.

The output of coal in 1905 was 7,959,000 tons. The estimated available supply is given as probably not less than 100,000,000,000 tons.

INDIA.—Coal is obtained in India in gradually increasing quantities from several provinces. The bulk of it is raised in Bengal, but it also occurs in large quantities in the North-West Provinces and Oudh, Punjaub, Central Provinces, Assam, Burmah, Umaria in Central India, the Nizams Dominions and Baluchistan.

The principal coalfields may be divided as follows:—

Eastern Fields. These include Karharbari, Raniganj, Barratrai, and Jherri.

Central Fields. North and South Karanpura, Daltonganj, Hutar, Umari, Warora.

Southern Field. The Singareni Field.

An accurate estimate of the exposed area of the fields has not so far been made, but it is given by certain geologists at about 35,000 square miles.

The coal in the various fields is not always of the same geological age. That of Peninsular India is almost entirely of Triassic age, whilst that of Extra-Peninsular India is of Cretaceous and Tertiary age. In *Northern India* the coal-measures consist of the upper, middle and lower series, and greatly resemble those of England, being composed of sandstones and shales with beds of coal and ironstone.

The Raniganj is the most important field and is conveniently situated, as it lies at no great distance from Calcutta.

The coal seams as a rule are of great thickness and

very numerous, and though not so pure as British coals are nevertheless of good bituminous or semi-bituminous quality.

The output of coal in India in 1905 was 7,921,000 tons.

Lieut.-Col. R. N. Mahon estimates the quantity still available in the main fields at 9,085 millions of tons.

South Africa.—Although there is unmistakable evidence of the existence of coal in many parts of central and northern Africa, it is chiefly in the south of the continent that coal is worked to a considerable extent. In the Soudan, in Ashanti, in the Congo Free State, in Algeria and in Madagascar, coal has been found, but the fields are either so slight in area, or so far from the coast, as to prevent their thorough development. With the exception of the Tete coalfield on the Zambesi River no true coal of carboniferous age is yet known either in the northern and central areas just named, or in the more important fields nearer the Cape Colony.

Cape Colony, Transvaal, Natal, Orange River Colony.—In the Permo-Triassic rocks which exist over a great portion of these colonies, and which are known as the Karoo formation, coal is found of considerable value and is worked in the following districts:—*Transvaal.* At Vereeniging on the Vaal River; to the south of Middleburg; in the Germiston district east of Johannesburg at Bocksburg, Brakpan, and Daggafontein. *Natal.* To the north of the Tugela River at Newcastle, Dundee and Ladysmith. *Cape Colony.* Kronstad, Cyphergat and Indwe, Molteno and Sterkstroom. Also in *Swaziland* and *Rhodesia.*

Outcrops of coal, in many cases of great thickness, have been met with at various points along the plateau lying

between the Drakenburg Range and the Matiwane Mountains, and along the southern slopes of those mountains, between the Kei and Umzimkulu Rivers.

The output of coal in South Africa in 1905 was 3,219,000 tons, the greater portion of which was raised in the Transvaal. No reliable estimate of the available coal resources has so far been made.

AUSTRALASIA.—The total output for the Australian Commonwealth in 1905 amounted to 7,496,000 tons.

New South Wales.—This is the most important coal-producing state in Australia, and is responsible for over 80 per cent. of the total output of the Commonwealth. Coal is found in several geological formations, and the most recent results are tabulated as follows by Prof. David, according to a valuable paper recently read by Mr. James Stirling (mining representative of Victoria).

Age.	Thickness Feet.	Formation.	Character of Coal.	Locality.
Tertiary	100	Pliocene to Eocene	Brown coal and lignite	Kiandra Bay, &c.
Mesozoic	2,500	Triassic	Coal only suited for local use	Clarence and Richmond River series
Palæozoic	13,000	Permo-carboniferous	Steam, gas, and household coal	Northern, Southern, and Western fields
	10,000	Carboniferous	Inferior coal	Stroud

The Kiandra beds of brown coal are about 30 feet thick. There are deposits at Forest Reef, near Nullathorpe, and

seams are also found in various alluvial beds covered by basalt. In the mesozoic formation are a series of rocks called the Lower Clarence Series, and these contain five seams of coal varying from 2 to 37 feet thick, made up of beds of coal about 1 foot thick interstratified with bands. In the Palæozoic rocks the Permo-carboniferous series is found, and this has been divided as follows by Prof. David :—

1. The Upper or Newcastle measures containing many of the best seams.

2. The Middle or Tomago coal-measures, in which are the East Maitland seams, 40 feet thick, of which 20 feet are workable.

3. The Lower or Greta coal-measures, with an aggregate thickness of 20 feet of workable coal.

Queensland.—The coalfields of this State are of both mesozoic and palæozoic age. In the former are the Ipswich and Barrum fields, believed to be co-related to the Clarence and Richmond River series of New South Wales. Near Ipswich the coal seams are more bituminous than further south; those of the south are good steam coals. An anthracite seam, 11 feet thick, has recently been struck on the Dawson River.

Coal is also found in *Victoria*, *Western* and *Southern Australia* and *Tasmania*.

New Zealand.—The total output of coal in New Zealand in 1905 was 1,586,000 tons, the greater portion of this being raised in Middle Island.

Middle Island.—The extent of the coalfield on the western side of this island is considerable. The seams belong to the Brown Coal Series, and are found interstratified

with bituminous shales, sandstones and limestones, very similar to the seams found in Germany. At Nelson and Canterbury and in Otago, brown coal is also found in large quantities.

North Island.—The measures in this island are probably of mesozoic age. Brown coal occurs in fairly large quantities, some seams being 10 to 15 feet thick.

Japan.

Large and important mines are now opened out in this country, the total output in 1905 being 11,895,000 tons. The mines are worked chiefly in the districts of Kinsin and Niphon. The coal is of good quality, and, like the coal-measures of China and India, is probably of Jurassic age. Other islands of these seas, as Formosa, the Malay Archipelago, and Borneo, have rich deposits of fuel, many of which are at the present time being actively worked.

China.

China is rich in many minerals, especially in coal, which is widely distributed throughout the vast Empire. Prof. Hull considers that the coal-measures are of an age more recent than the carboniferous, probably Jurassic. The chief provinces in which coal is found are: Pechili, Shan-si, Shan-tung, Ho-nan, and Hu-nan. Besides unparalleled riches in coal, many provinces have abundant deposits of iron-ore. Most of the coal is anthracite, of good quality, and there are probably larger deposits of this valuable variety in China than in any other country.

The *Shan-si Coalfield* covers an area of 55,000 square miles; thick seams of bituminous coking coals are found,

one seam being 20 feet thick. In Hu-nan anthracite coal, having a conchoidal fracture and comparable with the best varieties known, is found. The strata is greatly broken up in this district, and the inclinations are often great. Total area, 21,000 square miles. This great central coalfield of China stretches from Shan-si, near Pekin, along the frontiers of Chi-li and Shan-si provinces, through Western Ho-nan, and Hupeh to Southern Hu-nan. Detached areas exist in Manchuria, Shan-tung, Kiang-si, etc.

South America.

Coal in South America is chiefly found in the Secondary rocks, though a small quantity of carboniferous age occurs in the *Republic of Colombia*, in the *Argentine Republic*, and in *Patagonia*. In *Brazil*, coal of the Secondary rocks is found in the Santa Catania and Rio Grande do Sul Provinces. In *Peru*, *lignite* is worked to a small extent from the Tertiary, as well as from the Cretaceous and Jurassic rocks. In *Chili* lignite is met with in the Eocene rocks. Miocene lignite is found in the southern portions of Chili, and altogether this country now raises considerably over one million tons per annum.

CHAPTER VIII.

THE CLASSIFICATION OF COALS.

The essential properties of coal as fuel are determined by the product resulting from the decomposition, due to the geological processes, already described. But although these combustible products which are usually included under the general term coal have many characteristics in common, and there is a definite gradation of one form of fuel into another, still a wide dissimilarity is observable between most of the seams, both physically and chemically. It will easily be understood, therefore, that there is a considerable difficulty in establishing a method of classification which will give full significance to all important features, and at the same time be of practical everyday use in the naming of new seams or in the selection of coals for varied industrial or domestic purposes.

Modes of Classification. — Fuels are classified in different ways. Sometimes the classification is dependent upon the physical characteristics, such as colour, density, structure, and the behaviour of the coal when burnt, or the classification has reference to the age of the rocks in which the seams are found; or again, the method may be based on the chemical composition, while in other cases the calorific or heating power is the essential feature of comparison. Each mode of differentiation has certain advantages, either industrial or scientific, but the student often

finds great difficulty in distinguishing the varieties where the methods of doing so are based upon widely different standpoints.

CHEMICAL COMPOSITION.—That coal is derived from the decay of vegetable matter, and that the process is a gradual one, is shown by the following Tables, which are based upon the chemical composition of coal :—

COMPOSITION OF COAL (ANDRE).

Table I.

Substance.	Specific Gravity.	Carbon.	Hydrogen.	Oxygen and Nitrogen.
Wood	0·91	49·00	6·25	44·75
Peat	0·99	59·30	6·52	34·18
Lignite	1·25	72·37	5·18	22·45
Cannel	1·27	80·37	5·83	13·80
Bituminous . . .	1·30	86·17	5·21	8·62
Semi-bituminous . .	1·37	90·00	4·75	5·25
Anthracite	1·50	92·50	3·75	3·75

COMPOSITION OF COAL (TONGE).

Table II.

Fuel.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.	Available and Disposable Hydrogen.
Lignite, non-caking .	75·50	5·00	13·50	3·00	3·00	3·30
Cannel, Wigan, caking	80·50	6·00	8·50	2·00	3·00	4 94
Bituminous, caking .	85·00	5·20	8·20	0·60	1·00	5·00
Semi-bituminous, non-caking . .	90·00	4·17	2·53	1·72	1·58	3·86
Anthracite, non-caking . . .	93·50	1·50	2·60	O. & N.	2·40	1·20

The following Table, taken from "The Coal and Metal Miners' Pocket Book,"[1] gives the composition of fuels obtained from all parts of the world:—

COMPOSITION OF FUELS.

(Mechanical Draft, B. F. Sturtevant Co.).

Description.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ash.
Anthracite:						
France	90·9	1·47	1·53	1·00	·80	4·3
Wales	91·7	3·78	1·30	1·00	·72	1·5
Rhode Island	85·0	3·71	2·39	1·00	·90	7·0
Pennsylvania	78·6	2·50	1·70	·80	·40	14·8
Semi-bituminous:						
Maryland	80·0	5·00	2·70	1·10	1·20	8·3
Wales	88·3	4·70	·60	1·40	1·80	3·2
Bituminous:						
Pennsylvania	75·5	4·93	12·35	1·12	1·10	5·0
Indiana	69·7	5·10	19·17	1·23	1·30	3·5
Illinois	61·4	4·87	35·42	1·41	1·20	5·7
Virginia	57·0	4·96	26·44	1·70	1·50	8·4
Alabama	53·2	4·81	32·37	1·62	1·30	6·7
Kentucky	49·1	4·95	41·13	1·70	1·40	7·2
Cape Breton	67·2	4·26	20·16	1·07	1·21	6·1
Vancouver Island	66·9	5·32	8·76	1·02	2·20	15·8
Lancashire gas coal	80·1	5·50	8·10	2·10	1·50	2·7
Boghead cannel	63·1	8·90	7·00	·20	1·00	19·8
Lignite:						
California brown	49·7	3·78	30·19	1·00	1·53	13·8
Australia brown	73·2	4·71	12·35	1·11	·68	8·0
Petroleum:						
Pennsylvania (crude)	84·9	13·70	1·40	—	—	—
Caucasian (light)	86·3	13·60	·10	—	—	—
,, (heavy)	86·6	12·30	1·10	—	—	—
Refuse	87·1	11·70	1·20	—	—	—

[1] International Text Book Co., Scranton, Pa.

St. Louis Exposition Test.—An improved classification on the composition basis has been proposed by Mr. Campbell, as a result of exhaustive tests made by him on an enormous number of coals from the coalfields in every part of the world. The classification is based on the ratio of the contained hydrogen to the total carbon. This method admirably suited the whole of the coals tested, and a Table has been adopted containing nine groups, ranging from wood through peat and lignite to anthracite and graphite.

CALORIFIC OR HEATING POWER, *i.e.*, INDUSTRIAL VALUE.—The most generally accepted classification Table is that of Gruner. In this case the ash and water contents have been deducted, and the coals are taken as consisting only of carbon, hydrogen and oxygen, in order that the calorific and experimental heating powers of coals having nearly the same proportion of organic constituents, but varying in the quantity of ash and water, may be compared. In the Table given below, the calorific power was determined by the calorimeter and the evaporative power (kilogrammes of water in 0° C. vaporised at 112° C. per kilogramme of the pure coal burnt) was obtained by the amount of water evaporated in practical operations.

The nature and appearance of the coke in the first class was pulverulent, or at the most fritted; in the second class caked, but porous and very brittle; in the third class caked, moderately compact, and more or less swollen; in the fourth class caked, very compact, but little friable; and in the fifth somewhat slightly fritted, but more frequently pulverulent.

GRUNER'S CLASSIFICATION OF COALS (EXCLUSIVE OF LIGNITES) AS REGARDS THEIR INDUSTRIAL VALUE.

Names of the Five Types or Classes.	Real Calorific Power.	Percentage composition of the organic constituents.			Number of parts by weight of oxygen, taking H as 1.*	Weight of coke yielded by 100 parts pure coal.	Weight of volatile matters yielded by 100 parts of coal.	Evaporative power.
		Carbon.	Hydrogen.	Oxygen.*				K.
1st Class: Dry Coals, burning with a long flame.	8,000 to 8,500	75 to 80	4·5 to 5·5	15·0 to 19·5	3·0 to 4·0	55 to 60	45 to 40	6·7 to 7·5
2nd Class: Fat Coals, burning with a long flame, or Gas Coals.	8,500 to 8,800	80 to 85	5·0 to 5·8	10·0 to 14·2	2·0 to 3·0	60 to 68	40 to 32	7·6 to 8·3
3rd Class: Fat Coals, properly so-called, or Furnace Coals.	8,800 to 9,300	84 to 89	5·0 to 5·5	5·5 to 11·0	1·0 to 2·0	68 to 74	32 to 26	8·4 to 9·2
4th Class: Fat Coals, burning with a short flame, or Coking Coals.	9,300 to 9,600	89 to 91	4·5 to 5·5	5·5 to 6·5	1·0	74 to 82	26 to 18	9·2 to 10·0
5th Class: Lean (maigre) Coals, or Anthracite.	9,200 to 9,500	90 to 93	4·0 to 4·5	3·0 to 5·5	1·0	82 to 90	18 to 10	9·0 to 9·5

* This amount includes the nitrogen, which Gruner states rarely exceeds 1 per cent. of the organic constituents, but this is rather under the average amount.

It will easily be seen that the presence of ash and moisture considerably affects the comparative heating

values of fuels. It must also be remembered that oxygen does not occur in a free state in a fuel, but only in combination with other constituents, and no part of the fuel which is already oxidised will be capable of developing any further heat. Now, in order to estimate the value of a fuel from its chemical composition as a heat producer, it is necessary to allow for a certain amount of carbon and hydrogen, required to combine with the oxygen already present in the coal. If the oxygen combines with the hydrogen water is formed, thus, $H_2 + O = H_2O$; if with the carbon, then carbon dioxide will be formed, thus, $C + O_2 = CO_2$. As a rule the deduction is made from the hydrogen, the probability being that half of the hydrogen is used up in this way, leaving only a small quantity of *disposable* or *available hydrogen* (see Table II.) to assist in the combustion of the fuel by its combination with the oxygen of the atmosphere. Of course, hydrogen and oxygen when combined and forming water are very objectionable in any fuel, as this not only reduces the amount of available hydrogen, but causes a considerable amount of the calorific power of the coal to be uselessly expended in driving off the water.

In classifying coals, therefore, the moisture element has not to be overlooked, as it is a very important feature, especially in differentiating between the various kinds of bituminous coals and between bituminous coal and lignites, or between the lignites themselves. It is generally referred to as the "water of hydration," or that part of the volatile matter which is incombustible or inert, so far as the fuel value is concerned.

By means of Dulong's formula the heating value of coal

may be approximately ascertained from the chemical analysis, thus:—

$$\text{Heating value per lb.} = 146\,C + 620\left(H - \frac{O}{8}\right),$$

where C, H, and O are respectively the percentages of carbon, hydrogen, and oxygen. In this case the available hydrogen is represented by $H - \frac{O}{8}$. But even in this case the particular factor is somewhat indefinite, because the ultimate analysis usually contains the ordinary moisture as well as the water of composition.

The classification based on chemical composition, referred to as the St. Louis Exposition method, is on the whole a satisfactory one, judged from the industrial standpoint, but in certain cases is unsound. The exceptions occur in coals in which the hydrogen is from one-half to one per cent. above the normal, as often occurs in gas coals, while the percentage of oxygen is normal. In such cases the ratio is reduced below the correct values for such coals to a figure slightly different from that for lignites, as in the case of some bituminous coals. It is contended, therefore, by some,[1] that whilst the valuable fuel constituents of a coal are carbon and hydrogen, it is the percentage of oxygen in the fuel that indicates and determines its character; and that a ratio suitably combining the oxygen figure would eliminate the difficulty just mentioned. By dividing the percentage of carbon by the sum of the percentages of hydrogen and oxygen, the influence of the oxygen is at once seen in the new value (see table on p. 124).

Physical Characteristics.—The most common classifi-

[1] See Bulletin of Imperial Institute for 1906.

Locality.	Carbon, per cent.	Hydrogen, per cent.	Oxygen, per cent.	Ratio. Carbon, Hydrogen.	Ratio. Carbon, Hydrogen, Oxygen.
Lignite or Brown Coal:					
Thallern, Austria	65·15	5·05	29·80	12·9	1·87
Riestedt, Prussia	62·27	5·18	32·55	12·0	1·65
Wettenberg on the Oder	66·29	5·20	28·51	12·7	1·96
Hessen Cassel	66·49	5·33	28·18	12·4	1·98
Cannel Coal:					
Wigan	80·07	5·53	8·10	14·5	5·87
Tyneside	78·06	5·80	3·12	13·4	8·74
Boghead	65·72	9·03	4·78	7·3	4·76
Bituminous:					
Scotch:					
Wellwood	81·34	6·28	6·37	12·9	6·51
Kilmarnock, Skerrington	79·82	5·82	11·31	13·7	4·66
Eglington	80·08	5·50	8·05	12·3	5·50
Lancashire:					
Ince Hall, Pemberton Yard	80·47	6·68	7·53	12·9	5·66
Newcastle, Haswell, Wallsend	83·47	6·68	8·17	12·5	5·62
Anthracite Coals:					
Welsh, Nixon's Merthyr	90·27	4·12	2·53	21·8	13·6

cation of coal is that based upon its physical characteristics, such as colour, density, structure and its behaviour when burnt. Under this system fuels are generally divided into five varieties, viz., Wood, Peat, Lignite or Brown Coal, Coal, Anthracite.

Wood.—All fuels are derived from wood and the remains of plants, etc., which consist principally of cellulose, *i.e.*, the substance of which the permanent cell-membranes of plants are composed. The heating power of most kinds of

wood is about the same per pound, being usually taken at about ·4 of the value of the same weight of coal; in other words, 1 lb. of coal is equal to $2\frac{1}{2}$ lbs. of dry wood.

Peat.—This is the first product resulting from the decay of vegetable matter, the partly carbonised organic matter of bogs, swamps, etc. It contains chiefly ferns, mosses, rushes, reeds, and other similar plants. It is generally formed on river deltas, in low-lying marshy areas, or in pools or boggy places on moors or mountains. Near the surface it is generally of a spongy nature and light brown in colour, but deeper it is more thoroughly decomposed, and both darker and denser. Like other forms of fuel, its composition varies, being determined by the heat, pressure, time and geological conditions already referred to. The proportion of carbon varies from about 50 to 63 per cent.; of hydrogen from 4·5 to 6·8 per cent.; of oxygen from 28·6 to 44·0 per cent.; of nitrogen from 0·0 to 2·5 per cent. Unless specially prepared it generally contains a large amount of moisture, good air-dried peat retaining about 25 per cent. The ash varies greatly, but is rarely below 8 per cent. The calorific value of air-dried peat is about 3,000 calories, that of prepared peat or of peat briquettes being considerably higher. It is unsuitable for most metallurgical purposes owing to the phosphates and sulphur compounds contained in the ash, whether used in the form of briquettes or not. The specific gravity of peat varies from 0·11 to 1·02.

Lignite, or Brown Coal.—This is the connecting link between peat and bituminous coal. It is chiefly found in the Tertiary rocks, and is more often met with on the Continent and in the United States than in this country. It is, however, found at Bovey Tracey in Devonshire, in the

Miocene formation, and it is found in the same rocks on the Mackenzie River, Canada. As will be seen from Table I., it has lost about half of its oxygen; the percentage of moisture, on the other hand, is generally high, from 10 to 30 per cent. It has a lamellar or woody structure, having evidently shrunk but not having been compressed. Its colour varies from brown to black. Lignites may be divided into (1) Fibrous brown coal: this is fossil wood similar to German lignite; (2) Earthy lignite: this is without structure and with an earthy fracture; (3) Conchoidal lignite: this has a conchoidal fracture, but possesses no distinct vegetable structure; (4) Bituminous lignite: this has a conchoidal fracture, and somewhat resembles anthracite, being a black shining fuel, used largely for the production of gas and tar. It burns easily, with a yellow flame, and emits a disagreeable odour. Its heating power is low, and it leaves considerable ash. Its specific gravity is 0·5 to 1·0. The calorific power of the above-named lignites varies from about 5,000 calories in the case of fibrous to 7,000 in the case of bituminous lignite.

Coal.—The chief varieties of coals are Gaseous, Semi-bituminous and Anthracite. It has already been pointed out that the gradation of one form of fuel into another is so gradual that definite distinction is almost impossible. This is especially the case in the passage of lignite through bituminous lignite to what are known as the non-caking bituminous coals. Certain characteristics are common to both, so that terms derived from such characteristics are found to overlap certain varieties. This is notably the case with the gaseous coals, as this term would include lignites rich in volatile matter.

Gaseous.—This name is generally given to those coals which give off large quantities of volatile gas when heated, such as *Cannel, Hard Coal, Brown Coal.* Some of them are really Bituminous coals of the caking variety. They are generally conchoidal in structure, of a brownish black colour, although when ground to powder they are quite brown. They are free burning coals, giving a long candle-light flame, and may be either of the caking or non-caking varieties. The non-caking varieties most nearly approach the lignites, and when subjected to dry distillation leave 55 to 60 per cent. of powdery or dusty carbonaceous residue (coke). The calorific value is from 8,000 to 8,500 calories. The caking variety is rich in volatile matter, giving off 32 to 40 per cent. on distillation and leaving 60 to 68 per cent. of a friable, porous coke. The calorific power varies from 8,500 to 8,800 calories.

The best known variety of gaseous coal is *Cannel.* It is sometimes called "candle coal," from its readiness to light and burn with a bright steady flame. In Scotland it is called "parrot coal" because of the crackling or chattering produced when it is heated. It differs from ordinary bituminous coal in its texture. It is very compact, it is dull in appearance, does not soil the hands when handled, and has no appearance of a banded structure. It breaks with a smooth conchoidal fracture. It is rich in volatile matter, and is therefore used as a gas coal. It does not usually cake when heated and retains its ordinary structure.

The famous *Wigan Cannel* gives per ton the following results :—

14,111 cubic feet of 39 candle-power gas, 7 cwts. of good coke, and a large percentage of valuable bye-products.

The percentage of ash and sulphur is usually large. The calorific power, when free from ash and water, is from 8,000 to 8,500 calories.

Cannel, although differing so greatly from other coals, has a composition similar to certain bituminous varieties. It is clear, therefore, that the difference is chiefly a physical one, brought about undoubtedly by an unusual combination of heat, pressure, time and strata.

Boghead Cannel, or torbanite, is a mineral found in the coal-measures in certain parts of the Scottish coalfields. Some doubt exists as to whether it should be included amongst the varieties of coal, but considering its chemical composition and its geological position it is evident that it is merely a slightly altered form of ordinary cannel. It is brownish black in colour, with a specific gravity of 1·5 and usually contains 63 to 65 per cent. of carbon and 9·0 or 10·0 of hydrogen. It gives off large quantities of gas, in some cases as much as 15,000 cubic feet per ton, and when distilled at a low red heat gives off 60 to 70 gallons of mineral oil per ton.

As their name implies, gaseous coals are used almost entirely for the production of gas, the manufacture of coke, and the recovery of bye-products (*see* p. 240).

Bituminous.—The Bituminous coals contain more carbon and disposable hydrogen than the gaseous coals, but less oxygen, and also include both caking and non-caking varieties. There are three distinct varieties of Bituminous coals, viz., Clear Burning, Flaming, Fuliginous.

1. *The Clear Burning Coals* are similar in structure and appearance to the gaseous coals. They are generally very friable and break up into small regular lumps. The

flame from these coals is generally clear, and not so long as from cannel. Although the percentage of gas obtained from this coal is not so high as from other varieties, the large quantity of coke which is obtained when this coal is burnt makes a clear burning coal a valuable fuel for manufacturing purposes.

2. *The Flaming Coals.*—These are the true caking coals. Their structure may be said to be platey; they are very friable, and are known as soft coals. When heated the particles fuse together, forming a spongy mass of tarry substance, through which the gas escapes, and, when observed in an open grate, the gas is seen to spurt out intermittently as a narrow tongue of flame, followed by a small but dense stream of unkindled smoke. The result of this caking is that large quantities of excellent coke are obtained from this variety of bituminous coal.

3. *The Fuliginous Coals*, so called because of the sooty character of their flame, are also rich in volatile constituents, the gas obtained being of a good quality and large in amount. Their caking property is not so marked as in the flaming coals, and consequently the coke is of a poor quality, but the other residuals are greatly valued. Some varieties of this coal soften and swell up in the fire and on distillation leave 68 to 74 per cent. of swollen coke with 15 to 16 per cent. of gas. The calorific value is 8,800 to 9,300 calories.

These coals are used primarily for steam raising purposes, but they are also employed, or at any rate certain varieties of them are employed, for coke and smithy purposes, for gas making, and for ordinary household uses. When made into coke they are employed for the smelting of iron and

for condensing the fumes of hydrochloric acid produced in the manufacture of sodium carbonate.

Semi-Bituminous.—The varieties of coals included under this head are also called "steam" coals, "free burning" or "dry" coals. They are generally found below the bituminous and gaseous seams, and as they have lain longer in the earth it is probable that they have been subjected to greater heat and pressure through a longer period, and provided the nature of the surrounding strata has been suitable, the occluded gases have been to a great extent driven off (*see* pp. 14, 150). They contain, therefore, a greater proportion of carbon and a smaller proportion of volatile matter than the bituminous coals (*see* Tables I. and II., p. 125). The amount of carbon is sometimes as high as 92 per cent., and these coals gradually pass into true anthracite. Few countries are richer in steam coals than England and Wales; almost every coalfield has several seams which, though varying somewhat in the amount of impurities and ash, are rich in carbon, producing a free burning, non-caking coal which is of great value for steam raising, domestic, and metallurgical purposes.

Semi-bituminous coal is generally a good black colour, with a cuboidal fracture and harder than the varieties already mentioned. It kindles readily and burns quickly with a steady fire. The flame is usually short, sometimes entirely absent, and when burnt in a good draught very little smoke is emitted. The calorific power is from 9,300 to 9,600 calories. These coals are extensively used for steam engines and for manufacturing purposes of every kind. Those qualities free from ash are in great demand for household purposes. The best and almost smokeless

varieties are made use of on ocean-going steamers, and certain varieties, named the "dry" or "smokeless" coals, are used on the large naval steamers of this and other countries. The open-burning and flaming varieties found in North Staffordshire, which are very suitable for the manufacture of pottery ware, form another striking example of Nature's economical methods and the natural mineral advantages which this country possesses in various ways and in certain localities.

ANTHRACITE.—Anthracite is coal in its most altered form. Owing to the great geological forces to which it has been subjected, and the particular conditions of its deposition and formation, it has got rid of the bulk of its volatile constituents, so that it consists almost entirely of carbon (over 90 per cent.). It is a dense black in colour and has evidently been more completely mineralised. It is dense, hard, and lustrous. Its structure is homogeneous and it often flies to pieces when heated. It does not easily ignite, and burns with a feeble, smokeless flame, giving off intense heat. It is a non-caking coal, and although it leaves 82 to 92 per cent. of coke, this is of a powdery nature and of no commercial value. The calorific power of anthracite is 9,600 calories. Anthracite is used for smelting, and other metallurgical purposes; it is largely employed for heating kilns, such as malt kins, and for hop-drying, where a steady smokeless heat is required; for lime burning; and in the manufacture of water gas without purification.

CLASSIFICATION ACCORDING TO GEOLOGICAL AGE.—It is generally assumed that those coals which are found in the more recent Tertiary rocks are not so thoroughly

decomposed or metamorphosed, and, as a rule, those seams found in the carboniferous rocks have certain characteristics which are determined by their geological age or position. But at the same time it must be remembered that in some cases the same seams vary greatly in character if followed for some distance. This is well known to be so in the case of many seams in South Wales and the anthracite regions of America, where seams which are of anthracite quality at a certain point pass gradually into semi-bituminous seams within a comparatively short distance.

CHAPTER IX.

THE VALUATION OF COAL.

The industrial value of coal and its selection for certain purposes, while based largely on its chemical composition, is nevertheless also dependent on its physical characteristics and its behaviour when heated. The use of water-tube boilers, grates for burning small coal, fuel economisers, etc., is an indication of the great difference in the qualities of various coals and the necessity for adapting the mode of combustion to the fuel used, or *vice versâ*. The only certain guide in the selection of any coal for definite purposes must be continued and careful practical use.

It is quite evident that the suitability of a coal for any particular purpose needs careful consideration; anthracite, which generates great heat, is difficult to ignite, and therefore is not suitable, for example, for household purposes. It is clear also that a coal which will not coke is not the most suitable for gas production, as a great part of its value is lost if the coke is of poor quality. Besides the use of suitable coal it may be possible to gain a certain end by adapting the methods of combustion to suit the coal. This is done when an induced draught is provided or the coal is charged on to specially constructed grates, or when any of the means just referred to are employed. Another instance of this kind is that in which compressing and

charging machines are used for the more efficient manufacture of coke.

The value of coal of any kind is dependent upon—

1. The number of units of heat generated in its combustion (unless merely a gas coal).

2. The proportion of combustible material which it contains; or, in other words, its freedom from useless dirt.

3. Its suitability for the particular purpose for which it is required.

In the determination of the value of coals the following points, in addition to those already referred to in the classification of coal, should be considered:—

1. Moisture.
2. Ash.
3. Volatile combustible matter.
4. Nitrogen.
5. Coke and coking power.
6. Fireclay.
7. Sulphur and phosphorus.
8. Strength or hardness.
9. Specific gravity.

Moisture.—Moisture is an undesirable element in coal. It is an inert constituent and has no fuel value. On the other hand, as has been shown (p. 129), it greatly reduces the calorific effect. The exact determination of the amount of moisture present in varieties of coals is a very difficult matter, as some coals lose moisture rapidly when finely pulverised, while others have a marked capacity for absorbing moisture from the air. Even though great care is taken, therefore, in removing coal samples from the mine in hermetically sealed vessels, the moisture in the air of

the laboratory or the degree of fineness to which the sample is reduced affect the result of the test. Lignite coals generally show a greater percentage of moisture when taken from the waggon than when taken directly from the seam. Bituminous coals containing over 5 per cent. moisture generally show less moisture in the waggon than in the mine; bituminous and semi-bituminous coals containing less than 5 per cent. moisture generally show a gain of moisture in the waggons. In washing coal the great increase in the percentage of moisture would be a serious matter if it were not for the fact that special methods are adopted to dry the washed product. It must be remembered that 1 per cent. of moisture means 22 lbs. less fuel in each ton of coal.

Ash.—Ash consists generally of silica, alumina, lime, and oxide and bi-sulphide of iron. Like moisture, ash is also an inert constituent reducing the commercial value of the coal, requiring considerable labour for its elimination at the mine, and involving great expense in stoking, besides loss of fuel value at the place of consumption. It may be seen as a light white ash in the grates of houses, or as large "clinkers," fusible compounds, in the fires under boilers. Red ash, which is derived from the iron pyrites in the coal, is especially liable to fuse and to form clinkers. In this way the fusing vitreous mass accumulates on the grate bars, preventing the easy passage of the air; this is chiefly the case where great heat is necessary.

Volatile Combustible Matter.—The determining factor in the adaptability of a coal either for steam raising or gas production is generally the proportion of hydrogen. It will be noticed from the Classification Tables (I. and II., p. 125)

that not only does the percentage of carbon increase in the more complete metamorphism of the vegetable matter, but the ratio of the hydrogen to the oxygen also increases; that is, the percentages of oxygen and hydrogen are decreased, but the former more than the latter. The amount of hydrogen is the chief factor upon which the volatile combustible matter depends, and consequently also influences the production of coke. Again, when a large percentage of volatile combustible matter is present, coals ignite easily and usually burn with the long yellow flame to which reference has already been made. The quantity of moisture present in the coal affects the volatile matter. The moisture has a tendency to cause incomplete combustion, as the volatile matter liberated may not attain the ignition point, and, mixing with the gases from the burning mass, may pass away up the chimney unburnt. Bodies rich in carbon are also liberated by this lower temperature, which when mixed with air may inflame, but cause the separation of carbon particles which are not raised to the ignition point and which pass off as smoke. It must also be remembered that when coal is added to the fire, a considerable reduction of the surface temperature takes place. This cannot easily be avoided as it is due to the contact of the cold material, the volatile matter liberated causing an absorption of heat. The difficulty is increased if moist coal is fed into the fire.

Nitrogen.—The proportion of nitrogen in coal usually varies from about ·2 to 3·0 per cent. It cannot be said that its pressure greatly affects the coal except for bye-product recovery purposes. When burnt in coke ovens the nitrogen combines with some of the hydrogen of the coal to form

ammonia (NH_3). This is one of the compounds now valued very highly by colliery and gas companies, the economical recovery of which constitutes an important industry in this and other countries. Nitrogen in coal is probably derived from the remains of animals or from the atmosphere of coal-measure times.

SULPHUR AND PHOSPHORUS.—The presence of these elements in coal of whatever variety is generally a disadvantage. Whether sulphur passes off with the volatile matter in the production of gas or remains behind in the coke, it is a great drawback. In the first case the purification of the gas is rendered more difficult, in the second case the coke is of considerably less value for metallurgical purposes. Practically all the phosphorus and a large proportion of the sulphur go into the metal and contaminate it. The sulphur also tends to become converted into sulphuric acid through the formation of corrosive gases.

Sulphur occurs as a constituent of the organic fuel, as iron pyrites (bi-sulphide of iron FeS_2), often called "brassey," from its appearance when found in coal seams. In gas making, the sulphur occurring in this form is most likely expelled as sulphuretted hydrogen, carbon-bisulphide, or as some volatile organic compound. When coal is burnt in contact with the air the sulphur passes off as sulphur dioxide, or it may help to form clinkers in case it is oxidised to sulphate in the presence of a basic ash.

It occurs also as sulphate of lime, and alumina, and as an organic compound with carbon and hydrogen, in each case forming compounds of carbon, etc.

It is clear, therefore, that sulphur in any form is objectionable and should be got rid of entirely by washing or other processes. Its amount varies greatly in different coals. An analysis of several samples of coals gives the following:—

	Sulphur.
Welsh coal	1·43 per cent.
Newcastle	1·24 ,,
Derbyshire and Yorkshire .	1·01 ,,
Lancashire	1·44 ,,
Scotch	1·11 ,,
Anthracite (Ireland) . .	6·76 ,,

Caking and Non-Caking Coals.—In the Table No. II. (p. 125) it will be seen that the quantity of available hydrogen increases to a certain point, the amount of carbon also increasing similarly. But it is found that these coals do not cake, that is to say, the particles do not stick together in a plastic mass, when heated either in open grates or closed retorts. Consequently these coals are placed in the non-caking class. As the available hydrogen increases, however, beyond this point, it is found that these coals possess the property of caking together when heated, and forming a mass of coke when distilled in a closed retort. This coke is the residue of carbon left after all the other elements have been driven off either in the form of coal gas or coal tar. This may be called the caking class. It will also be seen from the above-named table that some coals rich in carbon, but with a less quantity of available hydrogen, do not possess this property, so we are led to the conclusion that the caking power of a coal depends not

upon the amount of carbon contained in it, but upon the quantity of available hydrogen.

COKE.—Coke consists of the residue of carbon and ash, which remains after all the hydro-carbons, oxygen, nitrogen, and water have been driven off. Although most coals produce coke, it is only from the caking variety of bituminous coal that the best coke can be obtained. There should be at least 4·5 per cent. of disposable hydrogen if a coal is to yield good coke.

If an ordinary pipe with a long stem be taken, the head filled with powdered bituminous coal, and the top covered with clay, so as to shut out the air, then if heat is applied to the head by means of a bunsen burner, the decomposition of the coal will take place. The coal splits up, the gaseous products, such as the lighter hydro-carbons, being emitted at the end of the stem, where they will burn if a light is applied. When the driving off of the gas is completed, and the clay removed, a mass of brittle and more or less spongy-looking carbon is found, which contains also certain quantities of inorganic matter called *ash*. This is coke, and may be called the charcoal of coal. Besides the lighter hydro-carbons already mentioned, however, other volatile compounds, the heavier hydro-carbons, etc., are produced, and these are collected when this process is conducted on a large scale as in gas making, and produce what are known as *tar* and *ammoniacal liquor*. From these many useful substances called *bye-products* are obtained.

FIRECLAY.—Fireclays are the clays which are found under many coal seams. They consist chiefly of silica and alumina, and will withstand great heat without vitrifying, and consequently, are of great value when made

into firebricks, crucibles, and retort pipes. Many mines of fireclay are worked for this product even where the coal above is of no commercial value.

Physical Characteristics of Coal and Coal Seams.—The structure and texture of coal is determined by its mode of deposition; the effects of earth movements which have taken place subsequently; and the proportion of the gases which have been occluded or driven out from it during decomposition, and these agents cause coal seams to vary not only in their chemical composition but in their thickness, structure, hardness, and the number of breaks, slips, cleats, or faces contained in them.

Some seams also contain bands either of shale or ironstone, representing *débris*, etc., deposited on the accumulations of vegetable matter. These may be situated at the top, bottom, or midway in the seam. Other seams are free from these "dirt bands" but contain quantities of "bass," *i.e.*, shale and organic matter intermixed, which is of no greater value. Considerable difficulty is always experienced in keeping the coal free from the former during extraction, whilst it is even more difficult to separate the "bass." Every effort, however, has to be made to do this, both in the mine and on the surface, as these impurities are an addition to the material which has been referred to as ash in considering the chemical composition. In some seams the dirt "parting," occurring at the bottom, in the middle or at the top of the seams, forms a good "holing" dirt, enabling the collier or the coal cutter to hole easily, in this way saving a considerable amount of coal as well as reducing the necessary labour. Holing in the dirt in this way is a distinct

advantage provided care is taken to remove the *débris* before the coal is allowed to fall so that the former does not get intermixed with the latter. In many mines the coal is of such a valuable character that the holing is never done in the seam itself, and if the dirt is very hard, coal cutters are used, probably at considerable expense, in order to avoid the cutting away of valuable coal. This is especially the case in thin seams.

The tenacity with which the coal sticks to the adjacent strata, that is, either the roof above or the floor below the seam, varies in different mines and in different parts of the same mine. Many seams are separated from the roof by a clear and smooth parting, which enables the coal to fall easily when undercut, only thin wedges being required to bring the coal down. On the other hand, many seams make an irregular and indistinct connection with the roof or floor, referred to as a "sticky" or "claggy" roof or floor, and this necessitates considerable labour during the disruption, the tenacity of the coal being apparently greatest where it is joined to the strata. This is especially the case where the roof is of sandstone and is "scabby" or uneven.

Seams are not always of the same hardness throughout their entire thickness. The upper portion may be of a very hard nature and the lower portion exceedingly soft or *vice versâ*. When the various parts of a seam differ in this way in texture, they may also vary considerably in quality. This is especially the case in thick seams where two, three or more distinct seams occur divided by thin or even imperceptible bands or partings, the difference in the character of the coals being very marked, some portions being of

first rate quality while others may be quite valueless. Seams are found having one portion of lignitic or cannel quality, while the other portion is of bituminous or semi-bituminous quality.

Strength and Hardness.—When coal has to be transported in tubs for considerable distances underground, tipped and handled at the pit bank, and carried on railways, roadways, canals, etc., it suffers considerable disintegration unless of a very hard nature. Hardness is therefore a valuable feature if waste is to be avoided. Soft coal produces large quantities of dust with every operation to which it is subjected. Besides, it absorbs more moisture and is more liable to spontaneous combustion where the conditions of transport are favourable to either of these deteriorating influences. Strong coal is needed especially in blast furnaces.

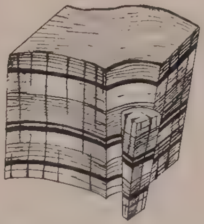


FIG. 23.—Structure of coal. The horizontal divisions are termed "laminations"; the most distinct vertical joints are termed "cleats" or "faces."

Lamination.—Owing to the deposition of the coal under water, the seams are generally made up of a number of thin plates or laminæ, which are parallel to the plane of stratification. This horizontal division is more marked in some seams than in others, being as a rule very distinct in lignites and bituminous coals, but entirely lost in anthracites.

Cleavage.—The "joints" or "faces" in a seam of coal or in a piece of coal are not all equally distinct. They have been caused by slight earth movements, which have also affected the superincumbent strata, or are due to the

shrinkage of the coal when drying. The most distinct vertical joint is called the "cleat" or "face." A second, but less marked joint is generally found either at right angles to the main cleat or at angles of slightly more or less than 90 degrees. The joints cause the coal to be broken up into rhomboidal blocks. The second and less distinct joint forms the "end" of the coal, and as the cleat is generally parallel to the "strike"—that is, the level direction of the seam—the face is usually at right angles to the strike—that is to say, parallel with the "dip" of the seam.

The Occluded Gases of Coal.—The gases enclosed or occluded in coal are distinct from the gases included in the chemical composition. They are the gases caused by the changes produced in the vegetable remains, which are pent up in the seams or adjacent strata until the face of the coal is laid bare or exposed, and the gases are able gradually to escape. They consist chiefly of carburetted hydrogen (CH_4), nitrogen, oxygen, carbon dioxide, hydrogen. These gases are included under the term "firedamp" by the miner, the chief constituent of which is CH_4 (about 90 per cent.). Great pressure is often exerted, as the gases force their way out of the pores or cavities of the coal or openings in the strata, and they often exert sufficient power to burst off large blocks of coal or rock. They may be heard oozing out of many newly-exposed faces of coal, and even out of large blocks of coal at the surface as they are broken up. Seams differ greatly in this respect, the transpiration of the gases, as the process of entering into the atmosphere of the mine is called, being slow and gradual in some cases, but rapid and violent in gaseous seams. The gases, after diffusion into the atmosphere of the mine, form with it an

explosive mixture, which is the cause of the serious explosions occurring from time to time. The fine particles of coal dust also, which are highly inflammable, and being readily turned into gas increase the danger considerably, as it is found that although mixtures of firedamp and air do not explode unless the proportion of firedamp is from about 6 to 12 per cent., mixtures of firedamp, coal dust, and air are explosive when only slight traces of the former are present, or even when firedamp is entirely absent.

Many experiments have been made to determine the nature and quantity of the gases occluded in coals. Prof. Meyer[1] placed pieces of coal of the size of a nut in a flask and boiled them in water which had previously been made air-free by boiling; the flask was provided with an indiarubber stopper, through which a glass tube led the escaping gases. The latter were collected over boiling water. He obtained from British and Westphalian samples, heated to 100° C., from 4 to 238 cubic centimetres of gas per 100 grammes of coal. The gases varied in composition, but all contained carburetted hydrogen, carbon dioxide, oxygen, and nitrogen.

Coals from Zwickau were tested, and gave off higher hydro-carbons in addition to the above-named gases. Mr. W. J. Thomas[2] extracted the gases by heating to 100° C. and afterwards exhausting them by means of a Sprengel air-pump. In this way he obtained 30 to 600 cubic centimetres of gas per 100 grammes of dry South Wales coal, the gas having a similar composition to that already mentioned. Some cannel coals gave only carbon dioxide and

[1] "Journal für Praktische Chemie," New Series, Vols. 4 and 5.
[2] "Journal of the Chemical Society," 1876, Vol. 30, p. 144.

nitrogen, others carbon dioxide, nitrogen, carburetted hydrogen, and higher hydro-carbons.

Prof. Jeller gives the following compositions, etc., of gases obtained from 100 grammes of Rossitz coal heated to 100° C. by the Meyer method:—

Sample.	Gas. Cubic Centimeters.	Carbonic Acid. Per cent.	Carburetted Hydrogen. Per cent.	Ethane, O2H6. Per cent.	Nitrogen. Per cent.
1 . .	54	56	3	16	25
2 . .	38	35	10	4	51
3 . .	60	36	25	7	32

From experiments made by Dr. Brockman,[1] as well as from those already described, coals may be divided into two types in regard to the gases enclosed: (1) those which contain higher hydro-carbons, and are dangerous; and (2) those which contain no higher hydro-carbons, and form a less dangerous dust. At the same time it must be borne in mind that the strata or cavities above or below the coal often form reservoirs of gas which has escaped from the coal seam, and these accumulations are just as dangerous when released as the gas transpired directly from the coal into the workings.

Specific Gravity.—As will be seen from the tables (p. 125), the specific gravity of coals varies considerably, being greatest in the most perfectly decomposed forms and least in the lignites. Specific gravity is only an important factor when there is restriction of space for storing or conveying, as in railway waggons and ships. A given bulk of

[1] *Gluckauf*, 1899, Vol. 35.

anthracite weighs from 10 to 15 per cent. more than an equal bulk of bituminous coal, but it is clear that the relationship of bulk to weight cannot be the determining feature unless the suitability of the fuel in other respects is not a consideration.

CHAPTER X.

FOREIGN COALS AND THEIR VALUES.

Although all countries require coal, comparatively few produce it, and fewer still produce such quantities of good fuel as to render the importation of further supplies unnecessary. There are probably only two countries—England and the United States—that do not import coal, for although such countries as Germany, France, and Austria raise enormous quantities of fuel annually, the coal measures are deficient in some varieties which are very suitable for specific purposes.

Nature has favoured the British Isles more than other countries in the formation, number, and character of her coal seams. This does not mean that every variety of British fuel is superior to other coals, but that this country has the greatest number of superior varieties. For example, class for class, the Westphalian coals are probably quite equal to English, except that the "Mager" coal is inferior in quality to Welsh Anthracite; but the number of varieties is less than in England. It is possible that the reputation of many varieties from this country is so good that sellers of coal from other fields have great difficulty in competing in foreign markets, but in their own markets the coal of France and Germany finds a large and ready sale. Again, the fact that the fuels of these countries are not suitable for so many purposes has caused Continental Mining

Engineers to devise means by which their usefulness may be increased, and by a careful process of cleaning, sorting, coking, and briquetting, the industrial value of their fuels has been greatly improved.

To show, however, that English coal is exported even to important coal mining countries, it may be stated that in 1903 the import of coal and coke into Hamburg from England was 3,067,400 tons, and from German coalfields 1,874,300 tons to the same place.

The manufacture of inferior varieties of coal into coke, especially in Germany, has greatly increased the value of the home product and the scope of its usefulness.

It is difficult to compare the value of the foreign coal with that of the home product; the exact conditions of charging and burning must be known if the calorific value, rapidity of combustion, production of smoke, and nature of the ash are to be of use for comparison, but a few examples of foreign coals, with an estimate of their commercial value, will be useful for comparison with British coals so far as this is possible.

Like England the **United States** possesses excellent seams of almost every known variety of coals, and as has been shown, these are of unlimited extent, and on account of the fact that in almost all cases the coal areas occur in close proximity to the seaboard, or to large industrial centres, the opportunities for its utilisation are numerous and varied, and the value of the commodity is therefore very great.

In the description of various fuels the American coals have already been compared (*see* p. 119), and it is only necessary to add the following table giving the average

composition and heating values of various coals obtained in the coalfields of the United States.

	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Brit. Th. Units.
Anthracite, Pa. . .	3·42	4·38	83·27	8·20	0·73	13,160
Broad Top, Pa. . .	0·79	15·61	77·30	5·40	0·90	14,820
Cumberland, Md. .	1·09	17·30	73·12	7·75	0·74	14,400
Pocahontas, Va. .	1·00	21·00	74·39	3·03	0·58	15,070
New River, W. Va. .	0·85	17·88	77·64	3·36	0·27	15,220
Connellsville, Pa. .	1·26	30·12	59·61	8·23	0·78	14,050
Youghiogheny, Pa. .	1·03	36·50	59·05	2·61	0·81	14,450
Pittsburg, Pa. . .	1·37	35·90	52·21	8·02	1·80	13,410
Hocking, Ohio . .	6·59	34·97	48·85	8·00	1·59	12,130
Fairmont, W. Va. .	1·61	27·16	67·54	3·69	0·68	14,976
Wyoming . . .	8·19	38·72	41·83	11·26	—	10,390
Oregon (lignite) .	15·25	42·98	33·32	7·11	1·66	8,540

As a rule the coal of **Germany** is characterised by a fairly low percentage of carbon and a comparatively high proportion of ash, soft irregular seams being more common than hard seams uninterrupted by rolls, varying inclinations, and alterations in the thickness of the seam. In the Ruhr coalfield the coal contains 82 to 85 per cent. of carbon and 5 to 6 per cent. of hydrogen. In Lower Silesia good coking coal is met with containing 84·0 to 87·0 per cent. of carbon and 5·2 to 6·0 per cent. of ash.

The heating value of this coal is as follows :—

	Calories.
Prosper Colliery	8,220
Ewald	7,300
Dahlbusch	7,200
Zollverein	6,800

In the Saarbrücken field the coal is of very good quality, containing up to 84 per cent. of carbon and 4·5 to 5·0 per

cent. of ash. A number of German coals tested by H. Bunte in 1900 gave the following analysis :—

Colliery.	Carbon.	Hydrogen.	O. & N.	Sulphur.	Moisture.	Ash.
Frohliche Morgensonne, Ruhr . .	89·27	4·41	2·74	1·25	0·70	1·63
Zollverein, Ruhr .	79·77	4·75	5·68	1·86	1·64	6·30
v. der Heydt, Saar .	69·07	4·21	10·93	1·12	3·90	10·77
Dudweiller, Saar .	78·26	5·11	8·57	0·97	1·32	5·77
Viktor, Silesia . .	81·12	4·24	4·93	1·23	1·65	6·83
Konigin Luise, Silesia	70·60	4·30	8·77	1·57	2·28	12·48
Oelsnitz, Saxony .	71·45	4·76	10·06	1·30	8·91	3·52
Penzberg, Bavaria .	47·78	3·83	10·92	5·24	10·18	22·05

German lignite is largely used for briquette making. For each ton of briquettes about 2·25 tons of raw lignite is required. The heating value of three tons of briquettes thus made is equal to two tons of bituminous coal.

In **Austria** the coal seams, though often occurring in the form of thick deposits of bituminous coal, are not greatly inferior to the German coals. The fuel of the Ostrau-Kirwin field, which may be looked upon as the south-west portion of the upper Silesian field of Germany, contains on an average 72 to 79 per cent. of carbon, 4·5 to 5 per cent. of hydrogen, 4·5 to 9·5 per cent. of ash, and 2 to 4 per cent. of moisture.

The lignite of **Bohemia** furnishes a very useful long-flamed fuel which is largely used in the iron industry of that country. Its analysis is as follows :—

	Moisture.	Ash.	Combustible Matter.	Heating Value. Calories.
Ossegg . .	19·90	2·55	77·55	5,546
Brux	27·83	2·91	69·26	4,775
Dux . . .	36·56	3·21	60·23	4,013

Hungarian coal is of poor quality in most cases. The best seams are at Kesicza-Szekul, and here the coal contains 60 to 70 per cent. of carbon, 4·5 to 5·0 per cent. of hydrogen, 0·8 to 1·5 per cent. of sulphur, and 6 to 12 per cent. of ash. Some varieties of Hungarian lignite contain 68·0 to 69·0 per cent. of carbon, 4·2 per cent. of moisture and 5·0 per cent. of hydrogen, the calorific power being as high as 6,960 calories.

The following table gives some typical analysis of **French** coals:—

	Fixed Carbon.	Volatile Matter.	Ash.
Lens	64·10	27·20	8·70
Commentry . .	60·00	34·00	6·00
Commentry . .	82·72	17·00	0·28
Blanzy . . .	76·48	21·24	2·28
Le Creusot . .	65·40	31·20	3·40
Gard . . .	59·50	26·60	13·90
Gard . . .	71·30	21·60	7·10
Var (lignite) . .	49·30	46·80	3·90

From the above it will be seen that the coals richest in carbon are found in the Commentry field, and these are equal to good British steam varieties. Many of the other classes make excellent gas and coking coals, while other varieties seem to be peculiarly suitable for the many iron and steel manufacturing processes, lime burning and glass making, for which St. Etienne, Creusot and other portions of Northern France are famous.

The **Belgian** seams are very similar in character and value to those of France. They may be classified as follows:—(1) Gas coal with 29 to 45 per cent. of volatile matter,

produced especially in the Mons coalfield; (2) Coking coal, with 17 to 29 per cent. of volatile matter; (3) Domestic coal, with 10 to 17 per cent. of volatile matter; and (4) Short flaming coal, with less than 10 per cent. of volatile matter, and used for lime and brick burning. The new Campine coalfield is now thoroughly explored, and numerous tests of samples show that the principal seams are of good gas-making varieties with some excellent coking seams.

The coal of **Russia** varies considerably in value; this can easily be understood as the fields are at great distances from each other. Moreover the opportunities for using the fuel are not in each case the same, and the impossibility of supplying and maintaining machinery for its proper utilisation greatly reduces its commercial value. In many cases sulphur is present in large proportions, as well as moisture and ash, two very undesirable ingredients, the latter no doubt largely due to the seams being interbedded with thin bands of shale and sandstone. The Trans-Caucasian seams are especially affected in this way, as much as 33 per cent. of ash occurring in coal which is otherwise of good quality and capable of making coke in spite of this defect.

The lignite found in the upper Miocene beds of **Italy** in the province of Pisa is fairly representative of Italian lignites generally. It contains 15 per cent. of ash, and 12 per cent. of moisture, but otherwise it is of good quality.

The lignite of **Greece** is also of good quality, and is used for heating boilers, for the calcination of ores and magnesite, and for the production of gas for illuminating purposes, though the latter is as a rule of a low value. The

following analysis of lignites from Greece may be taken as representative.

	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Ash.	Moisture.
Coumi . . .	48·86	4·24	0·65	2·07	10·40	10·08
Oropos . . .	38·09	4·03	2·51	9·21	19·44	13·72
Aliverion . .	40·24	3·32	0·97	0·64	7·59	18·69

In **Spain** many seams of good quality are worked. In the Belmez field the coal is suitable for gas and coke manufacture, though as a rule the coals are tender and make large quantities of small. An analysis of one of the seams in this district is as follows :—Carbon 75·00, Volatile matter 18·0, Ash 7·0.

Coal produced in **British Colonies** is on the whole of superior quality. In **Africa** many varieties are worked, all of which are suitable for locomotive or marine purposes when burnt under boilers adapted purposely to suit the character of the coal. Coal from Ballengeich in Natal, a sample of which was shown by the Natal Government at the Colonial and Indian Exhibition in London, gave on analysis :—

Moisture.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
1·68	10·84	71·32	0·88	15·28

Coal from the Stormberg district tested by the Government chemist in 1891 gave the following analysis :—

Moisture.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.
0·66	18·26	51·38	—	30·36

The coal is of a bituminous nature, burning with a long flame.

In the Indwe or Central coalfield, the chief coal seams are of considerable value, the analysis giving:—

Carbon	61·021
Hydrogen	3·028
Nitrogen / Oxygen	5·368
Sulphur	·434
Ash	30·320
	100·000
Coke	75·260

In the eastern or Tembuland coalfield an analysis of an important seam gives the following proportions:—

Fixed carbon	68·51
Volatile matter	9·50
Moisture	1·50
Ash	19·70
Sulphur	0·79

The analyses of other South African coals are as follows:—

	Fixed Carbon.	Volatile Matter.	Ash.	Moisture.	Sulphur.
Brakpan	63·50	25·05	11·36	—	—
Cassel Coal Co.	50·32	41·93	7·75	—	—
Middleburg	51·16	36·90	8·62	2·27	1·03

As a rule the incombustible matter found in South African coals is so intermixed with the fuel that great difficulty is experienced and considerable expense incurred in separating them. The coal would be of much greater

value and utility but for this fact, though it is likely that with more careful modes of extracting the mineral and the introduction of machinery for more thoroughly preparing it for the market its value would be greatly increased. The average selling price of Natal coal at the mine is about 12*s.* per ton, and of Cape Colony coal 15*s.* 6*d.* per ton, the former being 22*s.* or 23*s.* per ton at the ports of East London and Port Elizabeth, and the latter 24*s.* 6*d.* per ton at East London.

As a rule **Indian** coal contains more ash than European varieties, and its heating power is lower. The fixed carbon is seldom more than 60 per cent., though on the other hand some varieties are of excellent coking and gas qualities. The following table gives analyses of coals from the main fields :—

	Fixed Carbon.	Ash.	Volatile Matter.	Sulphur.
Raniganj (coking) .	59·0	11·9	29·0	1·89
Giridhi (coking) . .	60·9	9·9	29·0	0·40
Jherria (coking) . .	56·3	17·8	25·7	0·91
Singareni . . .	54·6	8·6	37·1	1·28
Umaria . . .	63·6	15·9	20·3	0·7
Mohpani . . .	50·8	11·9	37·2	1·0
Warora . . .	41·4	13·5	45·1	0·9

It has already been pointed out (p. 117) that many **Canadian** seams are equal to the best British steam coals, especially those of Nova Scotia. In New Brunswick the seams are bituminous, in Cape Breton they are of a good gas-making quality, in Queen Charlotte Isles bituminous and anthracitous seams are worked.

Some years ago careful analyses of Canadian coals were

made by Mr. Dawson, of the Government Geological Survey, and others. The coals of the Pictou (Nova Scotia) district are variable in composition, though chiefly bituminous in character. Two examples are:—

	"Roof Coal."	"Top Bench."
Fixed carbon	61·95	51·42
Volatile matter	25·87	24·80
Moisture	1·75	1·50
Ash	10·42	22·27

The best coal of this district analysed by Prof. How gave:—

Fixed carbon	66·50
Volatile matter	24·28
Moisture	1·48
Ash	7·74
Sulphur	·55

From this variety 8,000 cubic feet of 15 candle-power gas was produced.

Analyses of Cape Breton coals made also by Prof. How were as follows:—

Fixed carbon	64·59
Volatile matter	31·87
Ash	3·59

The seams in this coalfield are generally of excellent gas-producing varieties, burning with a clean bright fire in open grates, and giving off a large percentage of heat. When used for marine purposes they are found to ignite

quickly, to raise steam fast, to burn well and clearly, and to generate steam very efficiently.

The best **Australian** coal is found in New South Wales. Here many good varieties of steam, gas and domestic coal are found. The Newcastle measures contain large quantities of coal of all the above-named varieties, and these are not only used locally for steam-raising, household purposes, smelting, etc., but are exported in large quantities to many ports on the Indian and Pacific oceans. In Queensland the coal seams are of bituminous quality and are suitable for gas and coke making. To the south of Ipswich they are of good steam variety. An anthracite seam 11 feet thick is worked on the Dawson River. The Barrum coalfield, in which the coal is of good quality, but tender in character, is being rapidly opened out. In Victoria lignite occurs of Tertiary age, a bed of 150 feet thick being worked. In Western Australia non-coking bituminous seams are found in the Collie field in the Darling range of mountains.

Typical examples of **New South Wales** coals are as follows :—

	Fixed Carbon.	Volatile Matter.	Moisture.	Ash.	Sulphur.
Greta	54·41	39·21	2·25	1·41	—
Newcastle . . .	57·22	34·17	2·75	4·64	1·22
Lake Macquarie .	53·88	31·95	2·31	11·12	0·74
Illawarra . . .	61·61	23·65	1·03	13·17	0·54
Mountain . . .	52·34	34·18	1·95	10·12	1·41
Southern District .	58·60	24·87	1·96	14·04	0·53

Anthracite, as well as good bituminous seams, is found

in **Tasmania.** The following are analyses of Tasmanian coals :—

	Fixed Carbon.	Volatile Matter.	Moisture.	Ash.
Sandfly Ranges . .	67·00	12·70	5·40	14·30
Gardener's Bay . .	63·50	15·70	2·90	17·90

New Zealand coals are generally of excellent quality, yielding good coke with a low percentage of ash. Good lignite deposits are also largely worked and form an important branch of the coal-mining industry. The analyses of some typical New Zealand coals are as follows :—

	Fixed Carbon.	Volatile Matter.	Moisture.	Ash.
Buller . . .	74·68	21·51	2·61	1·20
Greymouth . .	53·03	41·95	0·99	3·98
Bay of Islands . .	57·29	36·00	4·60	2·20
Kaitangata . .	46·84	40·52	9·20	3·20
Shag Point . . .	43·15	33·70	14·40	1·00
Whangarei . . .	50·01	37·69	9·61	2·69
Malvern Hills . .	59·90	26·60	9·40	4·10
Green Island . .	35·70	39·80	23·10	1·40

The rich deposits of coal in **China** have already been referred to. The coal varies greatly in quality. In the south-western portion of Northern China the seams are anthracitous; in the eastern portion the seams change to bituminous. Of eleven varieties examined by F. Leprince Ringuet[1] two yielded excellent coke and two were good anthracites, the maximum percentage of ash being 21·2 and

[1] "Annales des Mines," 1901, Series 9, Vol. 19.

the minimum 5·3. In Southern China coal of very variable quality is worked. Coal of Tertiary rocks, which is anthracite on the coast of Tonkin, is bituminous in China. Its price in the Chinese ports is 8*s*. to 9*s*. per ton. The semi-bituminous coal of Tu-tse has a high percentage of ash but is used locally to a large extent.

The coal of **Manchuria** is of considerable value. In the Liao-yang field different qualities are worked, ranging from semi-anthracite to bituminous coking coal, and containing from 8 to 12 per cent. of ash. As a rule the coals are of a soft nature, large quantities of small being produced in working. An average percentage of Manchurian coals is given by Mr. W. A. Mollier[1] as follows:—

Fixed carbon	62·0
Volatile matter	26·0
Ash	10·0
Moisture	2·0
Sulphur	Traces.

Japan possesses many seams of good quality. In the south-west anthracite occurs, near Nagasaki. In the Island of Takashina bituminous coal is largely worked. The chief colliery in Japan is at Miike. An analysis of one of the best seams at that place gives:—

Fixed carbon . . .	58·00 per cent.
Volatile matter . . .	34·13
Ash	7·44
Moisture	0·35
Sulphur	2·73

[1] "Trans. Inst. Min. Engineers," Vol. 25, Part 2.

From the coke also, acetylene gas may be made by fusing the coke with lime in an electric furnace. By this means calcium carbide (CaC_2) is formed. When water is added to this compound, acetylene gas is produced together with pure lime. Thus:—

$$CaC_2 + H_2O = CaCO_3 + 6CH_2.$$

In addition to coke and house gas, the following, as already shown, are also obtained from the distillation of coal, viz.:—Water, coal tar, ammoniacal liquor and sulphur.

Coal Tar.—This is the thick, black, opaque liquid which condenses in the pipes leading from the distilling chamber, from which are obtained the following useful substances:—1*st light oil*, 2*nd light oil*, *heavy oil*, *green oil*, *pitch*.

Ammoniacal Liquor.—By the addition of lime and acids, the following are derived from ammoniacal liquor:—*Plaster of Paris, smelling salts, sal ammoniac.*

From the *heavy oil* of the coal tar *carbolic acid* is derived, but it is from the 2nd light oil that the most valuable bye-products are obtained.

2*nd Light Oil.*—This gives *benzine*, *toluine*, *xylene*, *artificial turpentine oil*, *burning oils*. From the *benzine* are derived (with nitric-acid) *nitro-benzine* and from the latter (with iron filings and acetic acid) *aniline*. It is from this product by means of various agents that the various *aniline dyes* are obtained, the recovery of which now forms such an important industry in this country and, more especially, in Germany.

Selection for Certain Purposes.—It may be said that

those coals are generally most suitable for *steam raising purposes* which have the highest percentage of carbon and possess, therefore, a higher heating capacity. This is only in case the conditions of grate, draught and mode of charging are properly suited to the fuel. It is clear that it would be useless to compare the different kinds of coal under the same conditions.

For *domestic* purposes two qualities are essential: (1) the coal should be clean, *i.e.*, free from dirt or ash; (2) it should be capable of giving a maximum amount of heat and light with the least amount of draught that may be supplied. It is also necessary that the coal should not burn away too rapidly even in a strong draught, as it is difficult to keep the temperature of a room constant with a rapidly burning fuel, and at the same time it is inconvenient and expensive to maintain. The chief coals used for domestic purposes are the semi-bituminous and bituminous varieties, such as the *Rhondda* of South Wales, the *Arley* and *Trencherbone* of Lancashire, etc. These are long flame coals, containing higher percentages of hydrogen and volatile matter than anthracite and igniting readily. They produce the warm, cheery effect which is of such great value in open grate combustion, while the smaller screenings, of semi-bituminous coals especially, are usually in demand for cooking purposes. Although anthracite is not largely used for household purposes in these islands, a large quantity of the Welsh anthracites—shipped to France and Germany—is used in the open house grates of those countries. Anthracite is carefully prepared before shipping for this purpose. It is passed through breaking machines, and then classified according to the various sizes produced, from

cobbles to French, Paris and German nuts, as they are termed. The smaller sizes are utilised for the manufacture of briquettes or patent fuel (*see* p. 241), and afterwards shipped in this form either for domestic or other purposes.

For *locomotives* semi-bituminous coals (*see* p. 137) are most suitable, as they produce great heat in comparison to their bulk, and, as the storage is restricted, this is an essential feature. It is clear also that a locomotive is not suited to burn coals which give off a large amount of smoke as, not only is the space too valuable for the accommodation of coal, a portion of which is destined to waste itself in the air, but it is also inconvenient to equip locomotives with smoke-consuming apparatus. Again, there is always the necessity for a high rate of combustion (*see* Chap. XII.) and a strong draught in locomotives, and bituminous coals are not suitable for such treatment, while, on the other hand, semi-bituminous coals are capable of giving a great amount of heat with a minimum quantity of smoke, and have the further advantage of burning so completely that soot is not deposited on the boiler tubes, a drawback which is inseparable from the lower grade coals. Semi-bituminous coals also ignite more readily than anthracitous coals (*see* Chap. VIII.), and it is thus easier to keep the heat constant.

Marine Purposes.—There are so many types of boilers used on steamships that it is difficult to define the most suitable coal for marine purposes, but in any case it is necessary, owing to lack of accommodation, that coals of high heating power should be used. As a general rule large sea-going vessels are constructed either (*a*) of sufficient

capacity to carry large quantities of coal, so as to accomplish the voyage in the shortest time possible, or (*b*) of smaller capacity and carrying less coal, but equipped, in other respects, for a voyage of longer duration. In either of these two cases it is evident that the coal used must have maximum heating power so as to avoid waste of valuable space on board ship or at dock or wharf side.

In ordinary steam navigation the semi-bituminous and higher calorific varieties of bituminous coals are used such as the *Duffryn*, *Rhondda*, *Merthyr* and others of South Wales; the *Silkstone* and *Barnsley Bed* of Yorkshire; and the *Wigan*, *Pemberton* and *Hindley* and other seams of Lancashire, etc. They include both the nearly smokeless and long flame varieties. For naval purposes the "dry or smokeless" steam coals which possess a slightly lower carbon percentage and a higher hydrogen percentage than the true anthracites are chiefly used viz., *Nixon's Merthyr*, *Neath*, *Aberdare Merthyr*, etc.

Iron and Steel Manufacture.—During recent years great attention has been given to the determination of the most suitable qualities and sizes of fuels for the various processes of iron and steel manufacture. It is not sufficient that the coal should be of the right quality and heating power and free from sulphur and phosphorus, but it is also necessary that it should be sized and cleaned thoroughly and should possess certain physical and chemical properties which will enable it to serve as a proper reducing or heating agent. For metallurgical purposes the chief coals used are the short flame bituminous or coking coals and the true bituminous coals, such as the *Nantyglo* and *Blaina*, the *Hafod*, *The Rhondda No.* 2, etc., of South Wales,

and many other seams in all parts of the British coalfields.

Coke (*see* p. 240) is also largely used for the manufacture of iron and for other metallurgical purposes, producing a great heat and generally being free from sulphur and phosphorus. When used for these processes it should be firm, tough and light, and should have not more than 1 per cent. of sulphur. For blast-furnace purposes dense coke is not so good as those varieties possessing large cell structure and hard cell walls.

GAS.—It was considered at one time that bituminous coal was the only variety suitable for gas-making purposes, but there are now such excellent processes and elaborate plant available for this industry that various classes of coal can be treated with advantage, each of which has some distinct use in gas production for which it can be employed. It is found that those coals which are not rich in the elements necessary for the production of illuminating gas may be suitable nevertheless for producing gas for heating purposes or for the driving of gas engines. On the other hand, many coals considered to be useless in gas making for illuminating purposes may yield large quantities of good coke. The improved plant and excellent methods referred to now make it possible to obtain in one form or another the whole of the useful elements which coal contains, either in the form of *illuminating gas*, *heating or power gas*, *coal tar* and *ammoniacal liquor products*, or *coke*. It is clear, therefore, that it is impossible to give the essential qualifications of a gas coal, as most of the various classes of fuel can be utilised with advantage.

The following gases are got from coal, or by its agency: (1) *Coal gas*, (2) *water gas*, (3) *producer gas*, (4) *power gas*.

Coal gas, also called natural or town gas, is produced by the distillation of coal out of contact with the air. It is composed of the following elements or compounds, but not always in the proportions named:—

		Per cent.
Carburetted Hydrogen	CH_4	40
Hydrogen	H_2	30 to 35
Carbon Monoxide	CO	6 ,, 8
Carbon Dioxide	CO_2	3 ,, 4
Oxygen	O_2	3 ,, 5
Nitrogen	N_2	7 ,, 8

Water gas is produced by passing steam through incandescent fuel (coal or coke), and consists usually of—

Carbon Monoxide	40 per cent.
Hydrogen	50 ,,
Carbon Dioxide	3 ,,
Nitrogen	4 ,,
Methane	5 ,,

And traces of other gases.

This gas is not suitable for illuminating purposes unless used with incandescent mantles, etc. It requires about half as much air as coal gas for its combustion, its calorific power being also about one half that of coal gas.

Producer gas.—The first or original form of producer gas was known as *Siemens*'. This is obtained by passing a limited supply of air over or through incandescent fuel.

Power gas is produced by passing quantities of air and steam through incandescent fuel. The gases produced by the two last named processes are somewhat similar and consist of carbon monoxide. The latter is used for power and heating purposes, while Siemens' gas is used chiefly for heating furnaces.

CHAPTER XII.

THE PRODUCTION OF HEAT FROM COAL.

It is well known that the chief value of coal lies in its use as a fuel, and by far the greater portion of the coal obtained is employed for this purpose (*see* p. 169).

A fuel may be defined as a substance, which when ignited, combines readily with oxygen; or, in ordinary language, burns and evolves a large quantity of heat during the process. The heat so obtained is made use of for a great many different purposes which may be divided into:

Domestic uses,
Industrial processes,
Production of power.

A number of these have already been referred to, and in this chapter the theory of the production of heat from coal will be considered, and its application to the production of power will be discussed.

The value of coal as a fuel depends mainly on the amount of heat which can be obtained from a given weight of it. This varies in different coals. The measure of this heat is spoken of as the *Calorific Value* of the coal, and as a rule it may be said the higher the calorific value, the higher will be its commercial value.

The calorific value of a coal, or the *Calorific Power* as it is also called, is the number of heat units available in one pound of the coal. There are two principal systems of heat

units in which quantities of heat are measured. In the first system, which is the one most generally adopted by engineers in this country, the heat unit depends on British standards of weight and temperature, and is called the British Thermal Unit, commonly written B.Th.U. (both in the singular and plural).

1 B.Th.U. represents the amount of heat required to raise the temperature of 1 lb. of water through 1° F. It has been established by physical science that, to a very high degree of accuracy, the amount of heat required to raise 1 lb. of water 1° F. is one-tenth of that required to raise it 10° F. and $\frac{1}{135}$ of that required to raise it 135° F. and so on; *i.e.*, that the heat required is proportional to the rise of temperature produced. It is also proportional to the weight of water heated, twice as much being required to raise 2 lbs. one degree in temperature as is required to raise 1 lb. one degree, so that to raise the temperature of 27 lbs. of water 119° F. requires 3,213 ($= 27 \times 119$) times as much heat as that necessary to raise 1 lb. 1° F., or in other words it requires 3,213 B.Th.U. The rule for finding the number of B.Th.U. necessary to heat up a certain weight of water from one temperature to another is therefore to multiply the weight of water in pounds by the difference in the two temperatures measured in degrees Fahrenheit, the product being the number of B.Th.U. required. In the second system, which is the one used on the Continent, and which is also universally adopted for purely scientific work, the heat unit depends on the metric standards of weight and temperatures and is called a *Calorie*. 1 calorie = the amount of heat required to raise the temperature of 1 kilogram of water through 1° C.

As in the case of the B.Th.U., the heat, measured in calories, required to raise the temperature of any given weight of water from one temperature to another is found by multiplying the weight of water in kilogrammes by the difference in the two temperatures measured in degrees Centigrade.

$$1 \text{ Calorie} = 3{\cdot}968 \text{ B.Th.U.}$$
$$1 \text{ B.Th.U.} = 0{\cdot}252 \text{ Calories.}$$

A third unit which is made use of in connection with the heating of boilers is called an *Evaporation Unit*, and is very much larger than the B.Th.U. It will be referred to later.

The calorific value of a fuel, as already stated, is the number of heat units available in 1 lb. of the fuel. That is to say, the calorific value of a fuel in B.Th.U. or calories is the measurement in one or other system of units, of the whole of the heat set free when 1 lb. of the fuel is completely burnt and the products of combustion (the gas given off and the ash left behind) allowed to cool down to the same temperature as the fuel had before ignition. Since a fuel which has a high calorific value should be more valuable than one having a lower, for more heat can be obtained from every ton of it, it is important to those who use coal as a fuel to know its calorific value as accurately as possible.

An instrument for measuring quantities of heat is called a *Calorimeter*, and calorimeters of special design have been devised for measuring the quantities of heat set free by combustion of fuel, or in other words for determining their calorific value.

One of these will be described later, but before doing so

it is necessary to give some account of the chemistry of coal and the theory of its combustion.

Chemists classify all known substances either as elements or compounds, compounds being those substances which can by chemical action or by the action of physical energy (heat, light or electricity) be shown to be a combination of two or more simpler substances which in their turn cannot, so far as is known to science, be further split up, and these latter simple substances are called elements.

Coal is a compound, but a very complicated one; in fact each variety of coal is really a different compound, and the composition of coal may be better understood if it is regarded as a combination of a number of elements and compounds existing in different proportions in different varieties of coal, some of them being present always and some of them only occasionally.

The principal element contained in coal, as has been shown, is carbon. The other elements are hydrogen, oxygen, nitrogen, sulphur and certain others, principally aluminium, silicon and iron, which remain behind after combustion, in the form of ash.

Exactly what compounds formed by the grouping of these elements actually exist in coal is a matter which has not yet been definitely determined and need not be considered here. Some of the hydrogen and oxygen is present, combined, in the form of moisture, and does not really form part of the coal although it has a certain effect on its value as a fuel.

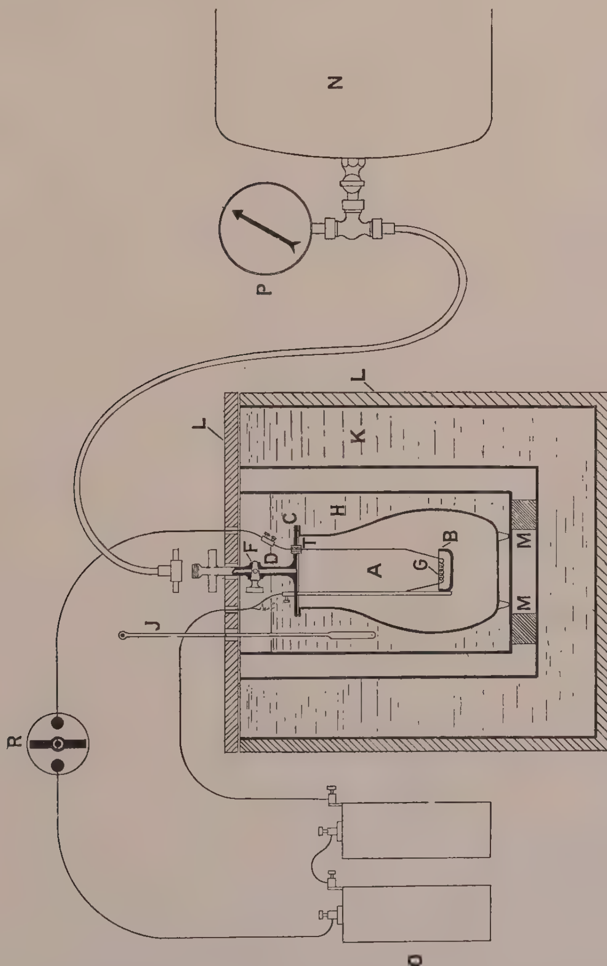
When coal burns, most of the elements combine to form compounds with the oxygen in the air and are given off in gaseous form. Those which do not combine with oxygen

or which form a solid compound remain behind as ash. It is found that in the combustion of coal, the oxygen of the air alone enters into combination with it, and so far as is known the nitrogen of the air has little or no effect on the composition of the products of combustion.

In determining the calorific value of a coal therefore, the combustion may be made either with air or with oxygen only. The oxygen in some cases is supplied to the coal direct in its gaseous state, and in others is obtained by means of an oxygen mixture; *i.e.*, a mixture of chemical compounds containing oxygen which readily gives up its oxygen to the coal on being ignited. The combustion is arranged to take place in a vessel surrounded by water, which absorbs the heat set free during combustion, and from a measurement of the rise of temperature of this water the calorific value of the coal can be obtained.

Mahler Bomb Calorimeter.—Probably the most accurate form of calorimeter is the Mahler Bomb Calorimeter. In this the coal to be tested is placed inside a strong closed vessel or bomb, usually made of steel and lined with platinum or gold, metals which are unaffected by oxygen or the products of combustion. Oxygen under pressure is forced into the vessel, and the coal being ignited by electrical means, combustion takes place, and the heat generated is absorbed by the water in a vessel surrounding the bomb. During and after combustion the pressure inside the bomb may become very great, this being the reason for employing a strong vessel in which to carry out the combustion.

In Fig. 24 A is the bomb in which the coal is burnt: B is a small tray to contain the coal under test. It is supported by a rod, shown on the left, from the top of the bomb. The



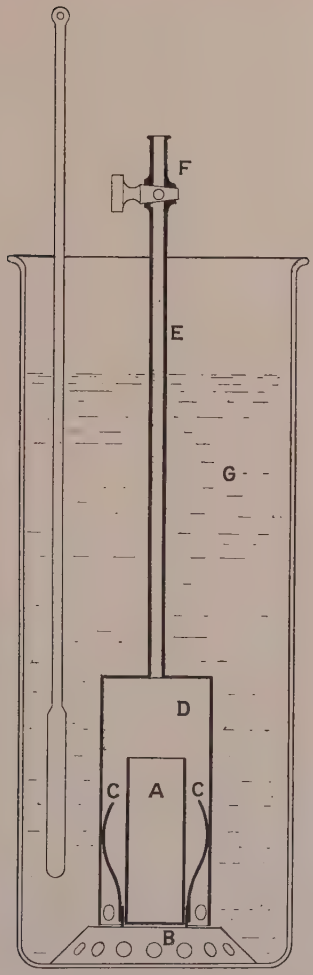
A Bomb.
B Coal tray.
C Top of bomb.
D Nozzle.
F Stopcock.
G Platinum ignition coil.
H Calorimeter tank.
J Thermometer.
K Outer tank.
L Covering of heat-insulating material.
M Blocks of heat-insulating material.
N Oxygen cylinder.
O Electric battery.
P Pressure gauge.
R Switch.
T Insulating tube.

FIG. 24.—Mahler Bomb Calorimeter.

top *C* can be removed from the bomb for the purpose of filling the tray, and is provided with a suitable joint so that when clamped on the body of the bomb the interior is

hermetically sealed. Attached to this top is a projecting pipe or nozzle *D* to which a flexible tube can be fixed for connecting the bomb with the oxygen cylinder *N* from which it is filled. This cylinder contains oxygen under very great pressure and is similar to those used in connection with the limelight lantern. The nozzle *D* is provided with a valve or stopcock *F*, of suitable design. Within the tray *B*, a coil of platinum wire *G*, for igniting the coal, is suspended, one end being fixed to the rod supporting the tray, the other end being brought up to the top of the bomb and taken through it in an insulating tube *T*. This end and the top of the bomb are provided with terminals and are connected to the battery *O*, through a switch *R*. The tube *T*, and the wire passing through it are fitted so as to be air-tight in order that no leakage may take place when there is pressure inside the bomb. The bomb is provided with feet, and stands inside the tank *H*, which is usually of copper, and is filled with water to a mark near the top. It is to this water that the heat of combustion is given, and from the observed rise in its temperature shown on the thermometer *J*, the calculation of the heat given up is made.

The tank *H* stands inside another tank *K*, which is provided with double walls, and is covered outside with felt or some other non-conductor of heat, *L*. The interior of *K* is filled with water. There is an air space between the vessels *H* and *K*, which serves to prevent, as far as possible, loss of heat from the outer surface of the tank *H*, as this means a loss of some of the heat of combustion, causing an error in its measurement. The tank *H* stands on small blocks of wood or other heat insulating material. An



A. Crucible in which combustion takes place.
B Base for supporting crucible and air-vessel.
C Clips for holding air-vessel in position.
D Air-vessel covering crucible and keeping it dry.
E Pipe communicating between air-vessel and outer air.
F Stopcock which when opened allows water to fill D.
G Beaker containing water through which gases produced by combustion bubble and so give up their heat.

FIG. 25.—Lewis Thompson calorimeter.

arrangement for stirring the water in *H* is provided (not shown in the illustration), and by its means the temperature is kept uniform throughout the mass of water.

The method of using the calorimeter is as follows :—

The sample of coal to be tested is broken up into a fine powder and very accurately weighed. The tray *B*, with the top *C*, is then removed from the bomb and the powdered coal placed in the tray. The tray and top are then carefully replaced and the top screwed or clamped tight so that the joint is properly made.

The oxygen cylinder *N* is next connected to the bomb, the stopcock on the bomb opened full, and that on the cylinder slightly. Oxygen flows from the cylinder to the bomb, and the pressure inside the latter rises, and can be read on the pressure gauge, *P*. The pressure to which it must be allowed to rise is calculated beforehand as follows :— The weight of coal to be burnt is known, and from it the weight of oxygen necessary for its combustion can be calculated. In order to ensure that the combustion shall be complete an amount of oxygen is admitted considerably in excess of that theoretically necessary. Having decided what quantity of oxygen is to be admitted, the capacity of the bomb, if not already known, must be determined by measuring the amount of water necessary to fill it. Knowing the weight of oxygen, the pressure at which this quantity will just occupy a volume equal to the capacity of the bomb must then be calculated, or obtained from tables. This is the pressure to which the oxygen is allowed to rise when flowing into the bomb from the cylinder *N*.

When a sufficient quantity of oxygen has flowed from the

cylinder into the bomb to bring the pressure up to the predetermined value the stopcock N is closed and the pressure at P observed. This will be lower than before the stopcock was closed. If it agrees with the pressure required, the stopcock on the bomb is closed, the water in H is stirred for several minutes, and the temperature read off on the thermometer. The switch R is then closed and a current flows through the platinum wire G, heating it to redness and igniting the coal, which burns away very rapidly: in fact the combustion is instantaneous. This instantaneous combustion is really the reason why oxygen is used instead of air, as with air the combustion would be impossible for some coals, and very slow in the case of others. For the experiment to be accurate, it is necessary to prevent heat escaping from the water in the tank, and this can only be done by making the duration of the experiment as short as possible. After combustion has started the current is switched off and the water kept stirred for some minutes.

Readings are taken every few seconds on the thermometer which rises rapidly at first and then more gradually, till finally it ceases to rise any further. This last temperature is noted, and the difference between it and that at the moment of igniting the coal gives the rise of temperature of the water. This rise of temperature multiplied by the weight of water gives the number of heat units taken up by the water from the bomb, but this alone does not represent the whole of the heat due to combustion from the coal. The bomb itself and the tank H have also had their temperature raised to the same degree as the water and have consequently absorbed some of the heat of combustion. To obtain,

therefore, the total amount of heat given off during combustion, the following method is employed :—

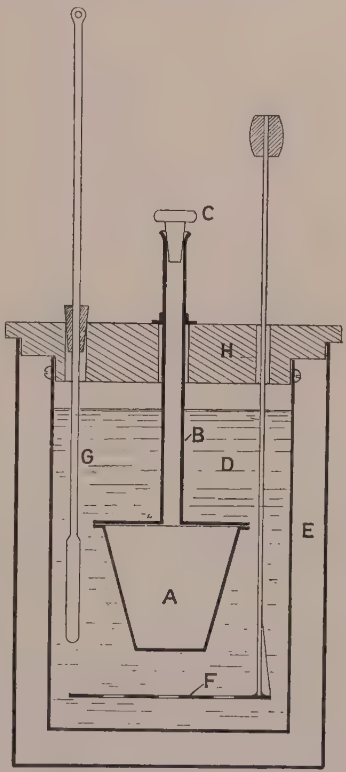
The calorific value of certain substances such as naphthalene and pure carbon (obtained from sugar) are known to a very high degree of accuracy. A weighed quantity of one of these substances is previously burnt in the bomb and the temperature rise due to its combustion measured with exactly the same quantity of water and in the same way as for the coal. Now the heat units given off by the burning of the substance are a known quantity, and by dividing them by the observed rise of temperature the number of heat units necessary to raise the temperature of the bomb, the water and the tank *H*, with the thermometer and stirrer, through 1 degree, are obtained. The quantity so obtained is called the heat equivalent of the calorimeter.

The rise of temperature produced by combustion of the coal is measured, and this multiplied by the heat equivalent of the calorimeter will give the total units of heat produced by the combustion. As the weight of coal is known, the heat units per lb. or calorific value can be easily calculated.

There are some small corrections to be made for the heat which is lost by radiation and conduction from the outside surface of the tank *H*. These heat losses depend on the difference between the temperature of the tank *H* and its surroundings. The water jacket tank *K* serves to keep the surrounding temperature constant, so that the cooling depends only on the temperature of the inner tank *H*, and by observing this every few seconds and noting the intervals between each reading, it is possible to calculate with considerable accuracy the heat lost from the surface of the inner tank during the whole of the experiment.

The bomb calorimeter is the most accurate for the determination of calorific values, and measurements taken by it are taken as standard, but it has certain disadvantages which preclude its use for practical coal testing. Its cost is very high, as the parts are expensive to manufacture, and it is necessary for the interior of the bomb to be plated with gold or platinum. The necessity of having a supply of compressed oxygen is also a considerable disadvantage.

To get over these difficulties a number of simpler and less expensive calorimeters have been devised, a great many of which, however, are far from accurate and therefore of little real value. They nearly all employ an oxygen mixture instead of oxygen gas. The best known of these is probably the Lewis Thompson calorimeter. One of more recent design which gives very good results is the Parr calorimeter.



A Combustion chamber.
B Pipe down which piece of red-hot wire is dropped to start ignition.
C Stopper.
D Tank containing water to which heat of combustion is given up.
E Outer vessel to prevent cooling of D.
F Stirrer.
G Thermometer.
H Lid of calorimeter.

FIG. 26.—Parr calorimeter, as designed by Mr. R. C. Wild, F.I.C.

There is another method of determining the calorific value of coals which differs from the calorimeter method, as it is indirect. The coal in this case is carefully analysed, and from its chemical composition the calorific value can be predicted by calculation with a fair degree of accuracy.

To explain this method it is necessary first to give some further account of the chemical composition of coal and the way in which this affects the heat generated by combustion.

A brief outline of the chemical theory necessary to understand combustion is all that will be attempted here. For a proper treatment of this subject the reader is referred to the standard works on chemistry.

It has been proved, and is one of the principles of chemical science, that the same compound always contains the same elements combined in a certain fixed proportion by weight. For example pure water which is a compound of the two gases hydrogen and oxygen always contains these elements in the fixed proportions of 1 to 8.[1] Another compound, carbonic acid gas, which is the chief product formed in the combustion of coal, consists of the elements carbon and oxygen always in the proportion of 3 to 8. Hydrochloric acid contains hydrogen and chlorine always in the proportion of 1 to 35·37; and so on.

From the proportions by weight of the constituent elements of a large number of compounds which have been analysed it is found that there is a further law governing the proportions in which the same element combines in different compounds containing it. This law, known as Dalton's Law, is that a distinctive number or weight can

[1] To be more accurate the proportion is 1 to 7·98, but this does not affect the principle now being illustrated.

be given to each element, and this distinctive number is such that in any compound consisting of two or more elements the proportion by weight of each element will be equal to its distinctive number or a multiple of its distinctive number.

Thus the distinctive number for Carbon is 12[1] and for Oxygen 16. They combine in the proportion of 12 to 16 to form Carbonic Oxide and in the proportion of 12 to 32 ($= 16 \times 2$) to form Carbonic Acid.

The distinctive number for hydrogen is 1. Hydrogen combines with oxygen in the proportion of 1 to 16 to form the compound hydrogen peroxide and in the proportion of 2 ($= 1 \times 2$) to 16 to form water.

Carbon combines with hydrogen in the proportion of 12 to 1 to form *Acetylene Gas*, in the proportion of 12 to 4 ($= 1 \times 4$) to form *Marsh Gas*, and also in the proportion of 12 to various multiples of 1 to form a number of compounds with hydrogen known under the general name of *Hydro-Carbons*. From a consideration of this principle of combination in multiple proportion, as it is called, Dalton deduced his *Atomic Theory*, and the distinctive number of each element he called its *atomic weight.*

This theory, briefly stated, considers all substances, whether solids, liquids, or gases, as made up of an innumerable collection of small particles to which the name *Molecules* is given. These molecules consist of one or more particles called *atoms*. In some elements the molecule consists of a single atom, in others of two atoms, and in some others of four atoms. The molecules of any

[1] These figures are given in round numbers; more accurately they are, for carbon 11·97, oxygen 15·96.

one element all contain the same number of atoms. In a compound the molecule consists of a group of atoms, and in this group there is present one or more atoms of each of the elements of which the compound consists. All the molecules of any one compound consist of exactly similar groups of atoms. The atoms of any one element all have the same weight, but the weights are different for different elements and are proportional to the distinctive numbers mentioned above. The weight of the atom of hydrogen is taken as a unit of weight, and the weights of all the other elements measured in this system of units will be equal to the distinctive numbers, hence the term *Atomic Weight.*

The chemical action of one substance upon another is explained by regarding it as an interchange or parting company of atoms in the molecules of the two substances; and although the recent researches of science tend to show that this theory is not the ultimate explanation of chemical action and the composition of matter, it nevertheless serves to express and to make intelligible the laws of chemical action.

When two chemical substances combine very readily with one another heat is given out during the process of combination. Fuels are those substances which combine so readily with oxygen that the heat given out is sufficient to raise the fuel to a state of incandescence. The amount of heat set free is found to be the same whenever given weights of the same two substances combine, provided they always produce the same resultant compound after combination. What is true for chemical action in general applies of course to combinations of different elements with oxygen. When carbon burns freely so that combustion is complete CO_2 is formed, *i.e.*, 12 lbs. of carbon combine with

32 lbs. of oxygen, and it is found that the same number of heat units are always set free by the burning of every pound of carbon to form carbon dioxide. This heat amounts to 14,500 B.Th.U. When hydrogen burns H_2O is formed, *i.e.*, 2 lbs. of hydrogen combine with 16 lbs. of oxygen (or 1 lb. with 8 lbs.), and it is found that the burning of 1 lb. of hydrogen always produces 62,000 B.Th.U. Carbon may be burned in such a way that carbonic oxide (CO) is formed and the combustion is then said to be incomplete, for the CO can itself be burnt, with the result that CO_2 is formed and further heat given out.

In the burning of 12 lbs. of carbon, $12 + 16 = 28$ lbs. of CO are formed, *i.e.*, 1 lb. of carbon produces $2\frac{1}{3}$ lbs. of CO, and 4,450 B.Th.U. are set free in this incomplete combustion of 1 lb. of carbon. It is further found that if the $2\frac{1}{3}$ lbs. of CO are now burnt to CO_2 10,050 B.Th.U. are set free, and it will be seen that the sum of the heat set free in the two stages of combustion to CO_2 (4,450 + 10,050) is equal to that set free when the combustion is carried out in a single stage (14,500).

It is possible by electrical means to split up water (H_2O) into oxygen and hydrogen again, and it is found that the electrical energy which has to be supplied in order to split up 9 lbs. of water is the exact equivalent of the amount of heat given out when 1 lb. of hydrogen is burnt to 9 lbs. of water. In the case of compounds combining with oxygen, the result of combustion is often to produce two other compounds instead of one. Thus, when a hydro-carbon such as marsh gas (CH_4) burns, the carbon and hydrogen part company and each combines with oxygen forming CO_2 and H_2O.

In 16 lbs. CH_4 there are 12 lbs. of carbon combined with 4 lbs. of hydrogen; so that 1 lb. of CH_4 contains $\frac{3}{4}$ lb. of C and $\frac{1}{4}$ lb. of H. When therefore 1 lb. of CH_4 burns, $\frac{3}{4}$ lb. of C are burnt to CO_2 and $\frac{1}{4}$ lb. of H to H_2O.

Three-quarters of a lb. of C burning to CO_2 produces 10,875 ($= \frac{3}{4} \times 14{,}500$) B.Th.U., $\frac{1}{4}$ lb. H burning to H_2O produces 15,500 ($= \frac{1}{4} \times 62{,}000$) B.Th.U., and it is assumed that 1 lb. of CH_4 in burning produces nearly $10{,}875 + 15{,}500 = 26{,}375$ B.Th.U. The actual heat must be less than this because some heat must be absorbed in parting the carbon from the hydrogen with which it is combined. In calculating the calorific value of coal containing carbon and hydrogen it is usual to take the sum of the two heats of combustion as representing the actual heat and afterwards to make a correction which varies with the composition of the coal.

The general principle underlying the method of calculating the calorific value from analysis is best explained by taking an actual example.

A coal is found on analysis to have the following composition after drying:—

Carbon	80·07 per cent. or	·8007 lb.	in 1 lb.	of coal.
Hydrogen	5·53 ,, ,,	·0553 ,,	,,	,,
Oxygen	8·08 ,, ,,	·0808 ,,	,,	,,
Nitrogen	2·12 ,, ,,	·0212 ,,	,,	,,
Sulphur	1·50 ,, ,,	·0150 ,,	,,	,,
Ash	2·70 ,, ,,	·0270 ,,	,,	,,

The carbon is taken first, and as there are ·8007 lb. present the combustion of it will produce $·8007 \times 14{,}500 =$ 11,610 B.Th.U. Hydrogen and oxygen are taken next,

and it is assumed that all of the oxygen is already combined with hydrogen to form H_2O. The reason for this is that the tendency for hydrogen to combine with oxygen is very much greater than that of any of the other elements present as might be inferred from its great heat of combustion as given above. So that in the sample taken there must be $\frac{1}{8} \times \cdot 0808 = \cdot 0101$ lb. of hydrogen already combined with oxygen. No heat is therefore available from this portion of the hydrogen, and account is only taken of the remainder, *i.e.*, of $\cdot 0553 - \cdot 0101 = \cdot 0452$ lb. of hydrogen. The heat of combustion due to this will be $62{,}000 \times \cdot 0452 = 2{,}802$ B.Th.U.

Nitrogen does not combine with oxygen during combustion of the coal so that no heat is derived from it, but as it is assumed to be in combination with one or more of the other elements in the coal, an allowance should be made for the heat absorbed in freeing it from combination.

The sulphur is assumed to burn to SO_2, and its calorific value is 4,000. The weight of sulphur being ·0150 lb. the heat due to its combustion will be $\cdot 0150 \times 4{,}000 = 60$ B.Th.U.

The ash is incombustible, and therefore considered as producing no heat. The total heat set free by the combustion of 1 lb. of the coal should be as follows:—

From Carbon . .	11,610	B.Th.U.
,, Hydrogen . .	2,802	,,
,, Sulphur . .	60	,,
Total	14,472	,,

From this must be deducted the heat necessary for splitting up the combination already existing of the available hydrogen with carbon, and also of the nitrogen from its combination with other elements. Instead of making this deduction as a separate calculation, it is customary to use a formula by which the nett heat available is calculated in one operation. Several of these formulæ have been devised, and the slight difference between their terms is usually an attempt to bring the calorific value as calculated by them more closely into agreement with that actually measured by the calorimeter. As a rule it is usual to take no account of the sulphur, its effect on the calorific value being very small. A formula which gives fairly accurate results is:—

$$\begin{matrix}\text{Calorific Value} \\ \text{in B.Th.U.}\end{matrix} = 146{\cdot}5\ c + 621\ h - 54\ (o + n)$$

where c, h, o and n represent the percentages of carbon, hydrogen, oxygen and nitrogen respectively present in the coal as determined by analysis.

This formula is not accurate for anthracite, the values obtained being too low.

Another and more recent formula, that of Goutal,[1] which is found to give more accurate results than the one above, is:—

$$\text{Calorific Value in B.Th.U.} = 146{\cdot}7\ c + \text{A} \times m$$

where c = the percentage of fixed carbon, *i.e.*, the coke with the ash deducted.

m = the percentage of volatile matter, *i.e.*, the percentage of coal after deducting the coke and water.

[1] See *Gas and Fuel Analysis*, by A. H. Gill.

A is a co-efficient depending on the amount of volatile matter m, as follows :—

$$\begin{aligned}\text{When } m &= 2 \text{ to } 15,\ A = 234\\ \text{,, } m &= 15 \text{ to } 30,\ A = 180\\ \text{,, } m &= 30 \text{ to } 35,\ A = 171\\ \text{,, } m &= 35 \text{ to } 40,\ A = 162\end{aligned}$$

The high percentage of carbon and coke in anthracite (*see* table, p. 125) is easily seen, as well as that of oxygen and volatile matter in the bituminous coals. The higher calorific value or evaporative power of certain bituminous coals is due to the large proportion of hydrogen present, of which the heat of combustion is about four times that of carbon.

Utilisation of Heat.—The methods of utilising the combustion of coal for the production of power may be classed as direct or indirect. In the first the coal is burnt in its natural state, and the heat so produced made use of. In the second the coal is first converted into gas, which is afterwards burnt, and the heat from its combustion utilised.

The direct method, which is the one most largely used, is applied by using the heat to produce steam from water contained in a boiler, the steam serving to drive an engine and so to produce power in its various forms—mechanical, electrical, hydraulic, compressed air, etc.

When water is evaporated or changed into steam, a considerable amount of heat is absorbed in the process, although the steam produced has the same temperature as the water from which it issues. This heat is called Latent Heat, and is measured in B.Th.U. It is a quantity which

varies with the temperature at which the evaporation is carried out, becoming less the higher the temperature, but is a fixed quantity for any one temperature. The temperature at which water boils depends on the pressure to which it is subjected. Thus, when water boils in an open vessel it has the same pressure as the atmosphere, and the evaporation temperature or boiling point is always 212° F.,[1] but in a boiler it may be very much higher than this. If the boiler pressure is 100 lbs. (above that of the atmosphere) the temperature will be 338° F.: at 200 lbs. it will be 388°. The units of heat absorbed in evaporating 1 lb. of water at 212° F. = 965 B.Th.U., at 338° = 876 B.Th.U., and at 388° = 841 B.Th.U. 965 *B.Th.U.*, the amount of heat necessary to evaporate 1 lb. of water at atmospheric pressure, is called a *Standard Evaporation Unit*. It is usual to state the efficiency of a boiler as regards transference of heat from the coal to the water as so many standard evaporation units per pound of coal.

Coals for use in boilers are classed as steam coals, and may be anthracite or semi-bituminous, or a mixture of these two.

A high calorific value, as has been shown, is the principal recommendation for a steam coal, but as it is impossible in practice to transfer the whole of the available heat in the coal to the steam, some loss being inevitable, calorific value is not the only point to be considered. The influence of the composition of the coal in reducing or increasing the loss must be taken into account.

[1] The temperature is always 212° Fahrenheit provided the barometer stands at 30 ins. If the pressure of the atmosphere varies from 30 ins. the boiling point will of course vary from 212° Fahrenheit.

The principal losses are due to :—

1. Incomplete combustion.
2. Unutilised heat which passes up the chimney in the gases from the boiler fire.
3. Loss of heat by radiation.

The first loss is influenced to a large extent by the composition of the coal; the second is indirectly affected; the third is only slightly affected. When combustion takes place in the boiler furnace the volatile matter is driven off and burns above the bed of the fire, where it requires air for its combustion. If this air is admitted above the fire, unless previously heated to a high temperature, it will cool the volatile gases below the proper temperature for their combustion, and a deposit of carbon or soot will be produced, which passes on to the chimney as smoke. Most of the hydrogen will also pass away unburnt. If the air is not admitted above the fire it must pass up through the fire, where most of it combines with the red-hot carbon, so that the amount which reaches the volatile gases is insufficient for their complete combustion.

The combustion of the carbon may be incomplete owing to carbon monoxide (CO) being formed instead of carbon dioxide (CO_2), and if the former is not supplied with sufficient air above the fire to burn it to carbon dioxide, it will pass on to the chimney and add to the losses. In order to get the fixed carbon to burn, the air must pass over its glowing surface at a high velocity, and if the fire is not very thick a much larger quantity of air may pass through than is necessary to consume the carbon. If the percentage of volatile matter is small, this air will pass on to the chimney unused, so far as combustion is concerned.

Now, in order to produce a draught in the chimney, the gases reaching it must have a temperature considerably above that of the atmosphere, and they therefore carry away with them a considerable quantity of heat. This heat is derived from the furnace, and is so much heat of combustion lost to the water in the boiler. The larger the quantity of gases passing up the chimney, the larger will be this loss, provided the temperature remains the same, so that by allowing more air to pass through the furnace than is necessary we increase the losses in the chimney beyond what is unavoidable.

Anthracite coals burn with a little or no smoke, while bituminous coals, owing to the volatile matter they contain, are difficult to burn without smoke, except in furnaces of special construction. Smoke, besides being a nuisance, means a loss of heat, for the particles of which it consists are simply unconsumed carbon, whose heat of combustion is thus lost.

Moisture in coal is a source of loss of heat in burning, for it must be turned into steam during combustion, and therefore absorbs a number of heat units, which pass away with it as latent heat. It also tends to increase the formation of CO instead of CO_2 from the red-hot carbon. All losses mean that the actual heat obtained in practice is less than the calorific value, so that more coal has to be burnt than would be necessary if there were no losses. In steamships space is valuable, and smoke is particularly objectionable. For this reason anthracite coal is largely used in the Navy and on ocean liners, on account of its smokelessness, its high calorific value, and its freedom from moisture.

The presence of ash in coal is a source of loss in burning and prevents the full calorific value of the coal being obtained in the boiler furnace for several reasons. It will be remembered that in measuring the calorific value the ash as well as the products of combustion were cooled down approximately to the temperature that the coal had to begin with. In the boiler furnace the ash is removed at the temperature of the furnace, which may be several thousand degrees Fahrenheit, so that with every pound of it a considerable amount of heat is lost. The ash also may enclose or form an envelope round a considerable amount of coal in such a way as to prevent its combustion, which means further loss.

If it contains much iron it will produce clinker, which is objectionable, because it closes up the spaces between the fire bars, thus stopping the draught, and it may also cause very rapid deterioration of the firebars.

Dirty coals with a very large percentage of ash, say 30 to 40 per cent., may have a calorific value of more than half that of good coal, and yet for the reasons stated above the heating effect in a boiler furnace may be extremely low, the heat from the combustion of the coal being only sufficient to raise its own temperature and that of the ash to the temperature of combustion, and to supply a surplus of heat which hardly exceeds that required to make up the chimney and radiation losses.

Indirect Methods of Power Production from Coal.—There are several indirect methods of using the heat of combustion of coal for the production of power. The coal may be converted into ordinary coal gas, coke-oven gas, or power gas, or it may be first converted into coke and the

coke afterwards converted into power gas or blast furnace gas.

The gas so produced is sometimes burnt in boilers for the production of steam, but the more usual and more efficient method is to burn the gas in the cylinder of a gas engine, the combustion being so rapid as to produce an explosion which actuates the piston and so drives the engine.

Coal Gas and Coke-Oven Gas.—Coal gas is suitable for use in gas engines as it has a high calorific value and it is clean, *i.e.*, it is free from dust and does not clog the valves or the inside of the cylinder with a tarry deposit. Its cost, however, is very much higher in proportion to its calorific value than gases classed as power gas, which have little value for illuminating purposes but are suitable for burning in gas engines.

Coke-oven gas is very similar to ordinary coal gas in regard to its composition. It is formed in the process of manufacturing coke from coal for use in blast furnaces, and is collected from the coke ovens. A portion of it is usually made use of for heating the ovens, but there is always a large quantity available for use in gas-engines which would otherwise be wasted. It must, however, go through a process of purification to free it from dust, tarry matter and other substances which would be deleterious to the internal parts of the gas engine.

Power Gas.—Power gas, as has already been said, is made in a number of different ways, the processes differing chiefly in the class of coal used and in the composition of the gas produced. In all the methods employed, air, or air and steam is passed over the surface of incandescent coal or coke in such a way that incomplete combustion takes

place. In the case where air only is passed, carbonic oxide (CO) is formed, and when steam as well as air is used, hydrogen is also formed by the splitting up of the steam. The heat necessary for the dissociation of the hydrogen from the oxygen is supplied by the incomplete combustion of the carbon to carbon monoxide. With these gases there is always a large percentage of nitrogen from the air. The vessel in which the production of gas takes place is called a *producer*, and gas manufactured in this way is often spoken of as *Producer Gas*.

The best coal for the production of Power Gas is anthracite, as with it little or no impurities are formed, and the gas may be supplied to the gas engine without the use of a purifying plant, which always means considerable additional cost and requires a certain amount of power to drive. Coke, too, makes clean gas. Bituminous coal can be successfully used, but it is always necessary to have a purifying plant in order to remove the tarry and other deleterious substances.

In the manufacture of *Mond Gas* bituminous slack is used and the purification is very complete, as one of the principal features of the process is the removal of the impurities. These impurities are of considerable value, the commercial success of the plant, to a large degree, depending on their recovery.

Suction Gas is a power gas in the production of which the air and water vapour are drawn over the incandescent fuel by the suction produced by the action of the piston in the gas engine cylinder. For the production of suction gas, anthracite or coke must be used, as up to the present it has not been practicable to use a purifier.

Blast Furnace Gas.—Blast furnace gas is produced from the coke used in the process of iron smelting. The gas produced consists chiefly of carbon monoxide, the furnace really acting much in the same way as a producer, working with coke and air. Usually the gas escapes at the top of the furnace and burns away to waste. By suitable means it may be collected. A portion of it is used for heating the blast, but the greater part is available for power production in gas engines. It is necessary to pass the gas through a cleansing plant in order to remove the dust which is the chief impurity.

Calorific Value of Gases Produced from Coal.—The calorific value of these various gases varies considerably even in the same kind of gas. The average values are as follows :—

Coal Gas for Town Lighting	600	B.Th.U. per cub. ft. at atmospheric pressure, 60° F.
Coke Oven Gas . . .	400	,, ,,
Mond Gas . . .	135	,, ,,
Dowson Gas . . .	150	,, ,,
Suction Gas . . .	150	,, ,,
Blast Furnace Gas . .	130	,, ,,

CHAPTER XIII.

WASTE OF COAL.

Although the uses to which coal is put are so varied and numerous and the power inherent in it is so great, it is nevertheless true that coal is capable of developing still greater power, and of yielding other valuable products. Again, although such a large quantity of coal is annually raised from certain coalfields, this does not represent the whole of the coal which has been explored or laid bare, as hundreds of acres of good coal are regularly being left in the mines, abandoned in such a way that the seams thus touched can never be again economically worked even if they do not greatly deteriorate in quality.

The waste of coal may be divided therefore into :—

Waste in working.

Waste in consumption.

Waste in Working.—The waste due to valuable mineral being left in the mine is far greater than that due to waste in consumption, and this avoidable or unavoidable loss greatly affects all engaged in coal mining, namely mine owners, royalty owners and workmen. Waste in working arises from :—

Coal left for support of surface and buildings.—A certain amount of coal has to be left in order to maintain shafts and to support houses, railways, canals, reservoirs and rivers on the surface. The amount left depends largely

upon whether the value of the coal is greater than the damage which would be caused by its removal. In some mines, after the removal of the seam, the whole of the spaces underground are packed or flushed by material sent from the surface. This enables a greater amount of coal to be removed without damage to adjoining property.

Barriers.—Much coal is lost through the practice of leaving unnecessary barriers between different royalties, or owing to the difficulty of arranging terms for the purchase of small areas of coal. In some coal districts numerous small properties occur with crooked boundaries, and barriers of great extent have to be left. In many cases these could be entirely avoided if satisfactory arrangements were made beforehand. Again, large barriers are sometimes left as security against an inrush of water or of foul gas, because plans of old colliery workings cannot be found. Efforts are made to avoid this difficulty by the systematic deposition of all plans at the offices of government inspectors of mines.

Water in Mines.—Coal is left ungotten because of contention amongst owners as to the expenses of pumping the water from the mines. In some coalfields central pumping stations are established by means of which the cost of pumping can be reduced and coal formerly abandoned may be recovered. In the county of Stafford a station of this kind is erected, and large areas of coal have been rendered productive which would otherwise have been unavailable at present, and ultimately would probably have been lost entirely.

Thick Seams.—In many thick seams the variation in the quality of the coal at different points is so great that large quantities of the less valuable qualities are left in such a

way that they are not likely to be worked at any future time. Sometimes thick seams are so difficult to work that unless the whole thickness is of uniformly good character, only the best will be extracted. Again, the whole of a thick seam cannot be taken out with safety, and part has therefore to be left for the support of the roof.

Undercutting the Coal.—In holing or undercutting coal, the collier has to cut away a fairly large proportion of the seam. This is to a large extent wasted as it is usually so small and becomes so mixed with the dirt of the mine that it is unprofitable to haul, wind and clean. In many mines mechanical coal cutters are employed merely in order that the undercutting may be done in the hard metal or fireclay beneath the seam, and in this way avoid the cutting away of a valuable seam of coal. Mechanical cutters are sometimes used to undercut in the coal itself where the strata above or below the seam is unsuitable, in order that the holing may not form so large a portion of the seam. It is doubtful whether this is an advantage, as the "cuttings" from many types of coal cutters are of the finest dust, and this is not only of no value commercially but is a source of danger in a gaseous or dry mine.

In addition to the above causes of underground waste, there are some others such as unsatisfactory mining leases, wrong methods of working, etc., all of which are to a great extent avoidable. It is likely that in the future many of these objections will be amended, and there is no doubt that the improved methods and appliances now being adopted in many British mines will result in the getting of a greater percentage of coal than that which is available under present conditions.

Although the amount of fuel stored in the coal-measures of this country is still enormous, it should be remembered that the resources are slowly but surely lessening, and, unlike all other agents that man possesses, it can never by any means be renewed or replaced. Long before the exhaustion of the fuel supplies there will be a very definite crisis, viz., when the best and uppermost seams have come near exhaustion and when conditions of temperature and pressure in the lower seams have rendered the extraction of the mineral more difficult and the cost of production much greater. When this takes place the cost of everything dependant upon coal—railways, shipping, manufactures, etc., will begin to be burdensome.

Waste in Consumption.—Many scientists contend that only one fourth of the power and wealth that is in coal is obtained from it by present methods, machinery and recovery processes. In other words, three fourths of all the coal which is won at such a great cost of life and labour is lost. It is remarkable that in proportion as modern science reveals greater power and wealth in the fuel, and invents new and varied applications of it, the appreciation of its waste increases. Thirty years ago it was considered that one half of the power inherent in coal was lost; at the present time and after the introduction of many efficient methods and appliances for utilising most effectively the heat derived from coal it is agreed that the loss is at least two thirds.

Waste of fuel in consumption might be avoided in many ways by alterations in the construction of flues and hot chambers whereby more complete combustion would be assured, with economy of fuel and increase of heat; improved

methods of stoking and of draught are needed and the introduction of grates or boilers suitable for burning certain qualities of large coal or slack which are at present considered worthless ; the utilisation of waste gases from coke ovens and the application of power gas (derived from the most inferior classes of fuel) to boilers or gas engines would enable large quantities of coal to be saved. Again, great saving could be effected by converting fine or duff coal from anthracite, gas, and other coals into briquettes. In Germany the advantages of washing coal have been most clearly recognised as a means of avoiding the waste of the fuel, and thus, by sending the mineral to the market freed from its impurities it is rendered at once more suitable for any purpose, and of much greater value. Mining engineers of Germany have paid great attention to the saving of coal and the vast volumes of black smoke passing away from furnaces, factories, locomotives, etc., which indicate only very partial combustion of fuel, are not so common in that country as they are in industrial parts of this country and on railways, or at sea.

Economies in the use of coal and the designing of machinery and plant which will secure its utmost utilisation will result in a great extension of the time during which the fuel supplies of this and other countries will be available.

Waste of any article of either intrinsic or relative value is reprehensible. Much more is it to be condemned when the article is both intrinsically and relatively of high value. A useful and even necessary article that can never be replaced must be intrinsically valuable. Such an article is coal.

CHAPTER XIV.

THE PREPARATION OF COAL FOR THE MARKET.

Until comparatively recent years most colliery proprietors were of the opinion that it was unnecessary to put the coal extracted from the mine through any cleaning or sorting processes, and the consumer was for a long time content to buy coal of an unsuitable size or containing considerable quantities of impurities. Owing, however, partly to the fact that German colliery owners, having many dirty seams to deal with, had adopted excellent means of cleaning the coal, British colliery owners have during the last few years adopted new and improved arrangements for preparing coal for the market. The coal is now more carefully handled at the surface, the different sizes and qualities are thoroughly separated, unclean coal and slack are washed, certain qualities are made into coke or briquettes, and in many cases valuable bye-products are recovered. It follows, therefore, that all thoroughly equipped collieries now have most elaborate heapsteads, efficient machinery and plant, and commodious surface buildings of every kind, all arranged so as to give the greatest economy in working and to secure the utmost utilisation of the coal; and it is in these operations that the colliery engineer looks to modern British engineering for such machines and plant as will enable him to do this still more efficiently and economically.

It is not within the scope of this book to describe the operations by which coal is extracted from the mine and wound to the surface, but a description of the whole of the processes to which the mineral is submitted after its arrival at the surface is necessary if the great efforts made by colliery engineers to supply an efficient fuel both to home and foreign markets are to be properly appreciated.

Handling Coal at Bank.—The handling of the coal at the pit bank has a great influence on the condition in which the product is sent to the market. To prevent undue breaking of the coal and to economise labour it is now customary to have the tubs containing the coal withdrawn at the surface from the cages in which they travel from the bottom of the shaft by automatic means, and to arrange the gradients of the rails to and from the cage so that the tubs will travel to the screen tipplers by gravity or mechanical means only. The tubs are caused to leave the cage by an arrangement of automatic catches. These are used in conjunction with automatic keps, or supports for holding the cage in position when it arrives at the top of the shaft, so that the strain of the weight of the cage and its contents will not have to be borne unduly by the winding rope. The catches are placed on the floor of the cage, and consist of heavy bars of iron running parallel with the rails in the cage on which the tubs stand. The bars are supported in such a way that when the heavier end is down the raised end is just the height of the tub axle. The tubs enter the cage from both sides, but are prevented from leaving it by the ends of the bars, until the cage arrives at the top or bottom of the shaft. Arrived at the top or bottom, the cage is allowed to rest on the automatic keps referred to, and at

P 2

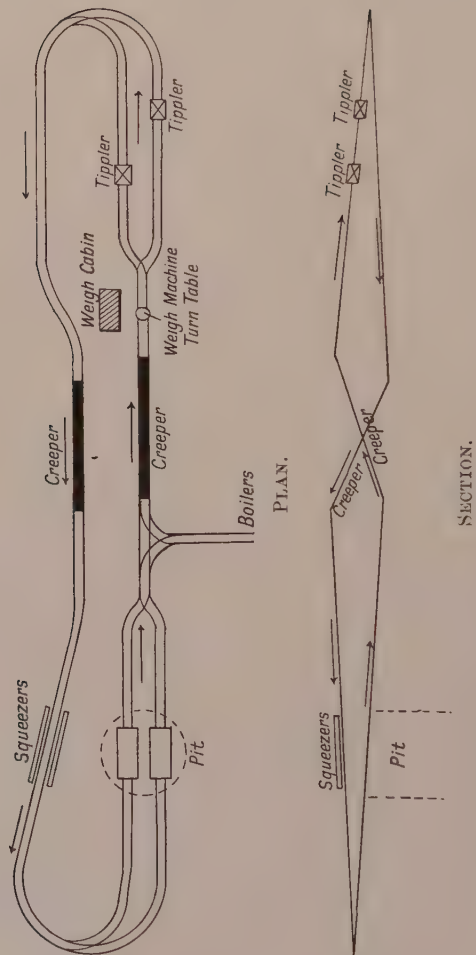


FIG. 27.—Arrangement of pit top for mechanically dealing with a large output of coal.

the same time a plate fixed to the cage rests upon the auxiliary keps. The plate supports the underside of the bars, and as the cage is lowered on to the keps a projection

supports and raises the plate, thus lowering the bars in the cage, whereupon the tubs are free to pass out of themselves, the rails in the cage being slightly elevated at the centre. A small lever placed between the rails, is caught by the axle of the tub as it passes, and this draws the extra

FIG. 28.—Creepers, for elevating tubs by mechanical means.

Reproduced by kind permission of Messrs. Heenan and Froude, Birmingham.

keps from under the plate fixed to the cage, which, together with the bars, immediately resumes its proper position and prevents further tubs from passing out. When the ordinary keps are afterwards withdrawn the cage is free to pass.

Having thus slowly and smoothly left the cage, the tubs pass to the weighing machine, then proceed a short distance

by the aid of gravity until they arrive at a point where a mechanically-driven endless belt or chain, called a Creeper, is operating. A projection or carriage on this creeper comes in contact with the axle of the tub and causes it to move forward up a short incline. Arrived at a sufficient height the gradient changes, and the tub runs slowly to a tippler placed above the screen belts. After being overturned and emptied, it passes out at the opposite side and runs back again to the cage, being again elevated by a creeper immediately after leaving the tippler if the height of the latter above the top of the shaft is not sufficient to render this operation unnecessary.

Various forms of tipplers are in use, but the best ones are constructed with a view to preventing the breakage of the coal as it is discharged from the tubs on to the belts, and to do the work more easily and quickly than was formerly possible. The latest forms of tipplers are driven either by power or gravity, and, by a reduction in the distance through which the coal has to fall, better means of inserting and withdrawing the tubs so as to save time and avoid jerking, and a more efficient separation of the small coal from the large as it descends the tippler bars, it is now possible to accomplish this important operation most efficiently and economically.

In the first, or gravity, type the tubs usually enter on one side of a squirrel-cage compartment, and, after being rotated and overturned, pass out at the other side. The action is simple and very economical. The tippler holds three (sometimes four) tubs, which rotate with the squirrel cage, this rotation being achieved by the weight of the loaded tubs. The mode of operation is as follows:—A loaded tub from

the weighing machine is run into the tippler with considerable velocity, the impact being sufficient to eject the empty tub already standing on the horizontal track. Two powerful brakes pass round the periphery of the tippler ends. These are under the control of an attendant. On moving the lever the brakes are lifted and the tippler rotates one-

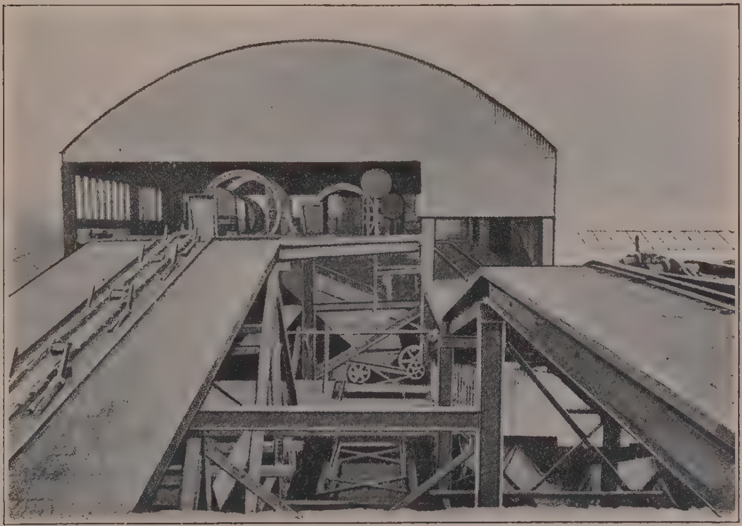


FIG. 29.—Tipplers for discharging coal from pit tubs on to screens.

Reproduced by kird permission of Messrs. Heenan and Froude, Birmingham.

third or one-fourth of a revolution, according to the number of tubs, being brought to rest at the next horizontal position. The particular construction of the tippler causes a temporary hopper to be formed, into which the coal is discharged, and from which it is gradually emptied owing to the slow and steady movement of the arrangement. The coal is thus prevented from falling through any distance,

and is not subjected to any rapid or other damaging treatment.

Power-driven tipplers, operated either by steam or electricity, are now largely used at the best modern collieries. They are usually of single-compartment design, made to operate automatically, constructed so that there is only a slight distance through which the coal has to fall to the screen chute and formed to operate quickly and smoothly and with little interference of the operator. They are also arranged to deposit the coal in the chute in such a way that very efficient separation of the small from the large coal takes place as the mass descends.

Screening.—The screening of the coal includes all the processes adopted for separating the various sizes; extracting, by mechanical means only, particles undesired by the consumer; and the reduction of the run-of-the-mine (that is, all coal coming from the mine) to a uniform size. For these purposes it may not only be necessary to pass the coal over or through the various separating or sorting belts or machines and to pick impurities out by hand, but it will probably also be advisable to break up or crush the coal so that it may afterwards be more thoroughly separated or made more valuable commercially because of its uniform size. Under ordinary circumstances the coal, after leaving the tippler, passes by means of bars or shoots on to the picking belt below. The effect of using bars is to cause all coal of a less size than the space between the bars to fall through the latter and thus become at once separated, passing to another portion of the screens, where it is treated separately. While travelling on the belt the dirt is picked

out by women or men, and then the coal passes from the belt to the waggons.

It is not often unnecessary to pick the coal, but in a few cases the coal is passed over a Fixed Bar Screen, which

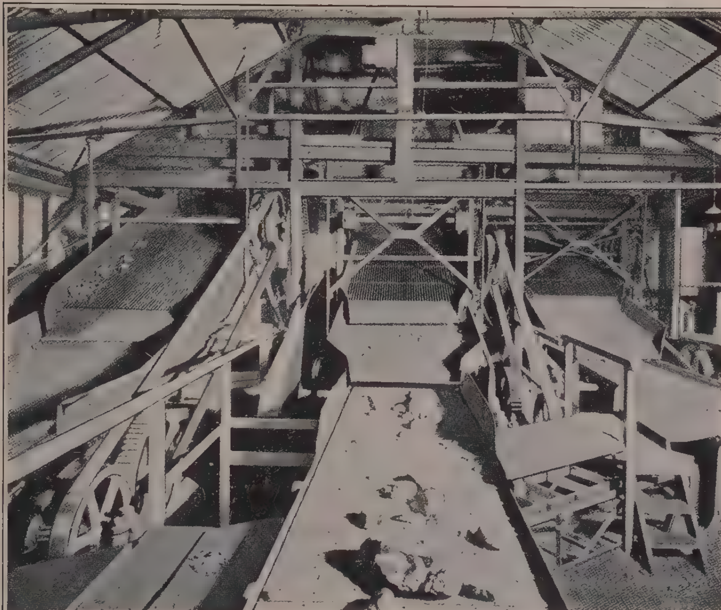


FIG. 30.—View of interior of screening shed, showing jigging shoot, screens and belts.

Reproduced by kind permission of Messrs. Heenan and Froude, Birmingham.

simply separates the various sizes, and each size passes separately into carts or waggons, or it may be passed through a Sizing Trommel direct into the carts or waggons, as shown in Fig. 32.

A Fixed Bar Screen is constructed of mild steel plates and tapered screen bars, fixed at such an angle that coals

FIG. 31.—Ackton Hall Colliery, showing screening belts and driving gear.
By kind permission of Messrs. Head, Wrightson & Co., Stockton.

gently descend direct to trucks or picking belts. The screen bars are tapered, the widest part being uppermost, so that coal cannot become wedged between them, and the pitch is arranged to suit the various sizes required. To prepare the mass of coal as it leaves the tub for more thorough screening, a jigging shoot or jigging screen may be used, consisting of a box-like arrangement constructed of steel plates or bars (Fig. 31) and angles, and suspended by means of hanging rods, in front of screen to receive the coals from same and distribute them gradually and evenly over the belt. In this case all coal passes on to the belt, but in a condition which enables it to be more readily picked or screened. The shoots are oscillated by means of eccentrics.

Jigging screens are now largely used which combine the advantages of both bar screens and jigging shoots. They not only enable the coal to be distributed evenly and without great breakage on the belts, but act as a screen through which the smaller sizes may pass. They are merely inclined wire grids or perforated plates, shaken from side to side by means of eccentrics in a manner similar to that adopted in jigging shoots.

Where the screening described is not sufficient to entirely separate the various sizes of coals, whether for subsequent washing or otherwise, Sizing Trommels are used, a good form of which is shown in Fig. 32. The mesh of the trommels is arranged to suit the particular material being treated, and the size of the trommel is determined by the output required. A centre shaft is supported at both ends and driven through a toothed rim attached to the shell or by a chain-wheel and driving chain. The screens of the trommels can be arranged in a line or inside each other, as

in illustration (Fig. 32). The coarser coals remain inside the inner screen, the next size less passes only through the inner screen, the medium size through the second screen, the finer coal passes through all the screens, and it is a simple matter to arrange for the delivery of the various sizes into their respective hoppers.

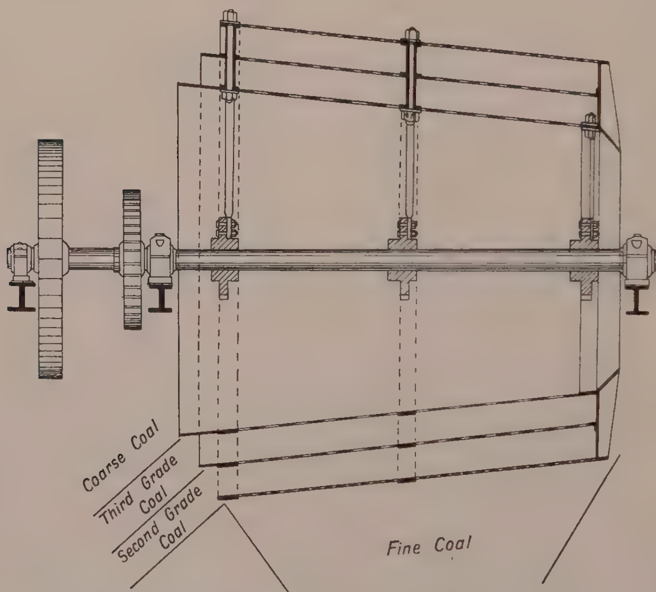


FIG. 32.—Sizing trommel for separating various sizes of coal.

Recently "sizing grates" have been introduced into this country from Germany, and these are employed where a large quantity of coal is required to be sized rapidly, thoroughly and without breakage. They consist of a special moving screen of very simple construction, the screen being formed so that the material may be

Fig. 33.—Ackton Hall Colliery, showing heapsteads, screens, shunting arrangements.
By kind permission of Messrs. Head, Wrightson & Co., Stockton.

lifted from one roller to the next without shock, and in such a way that the pieces which do not pass through the apertures do not get crushed or jammed between the bars.

A number of these grates are used in conjunction and arranged for the sizes required.

Shaking tables are used for the purpose of more thoroughly screening the coal than can be done by ordinary screen bars. The principal advantage of such apparatus is that they work without any shock either on foundation or framing, so that they may be used without there being any danger of vibration or damage to the building in which they are placed.

The shaking table is provided with straight inclined sieves resting on four vertical pillars, mounted in ball bearings, the upper sieve being supported and the lower one suspended. Horizontal circular motion is imparted to the table by means of two vertical crank shafts driven by bevel wheels. Through the rotary motion and the inclined position of the sieves the coal is given a slightly oscillatory and descending motion, whereby the various sizes, and especially the dust, are separated. Thus the coal is exposed to little shock, and the product obtained is very free from dust. The small leaves the shaker below, and the sized pieces leave at the end or sides as required. The output of such a table is about 160 tons per hour.

Disintegrators.—It is only quite recently that the advantage of crushing or breaking coal before screening or washing has been recognised in this country. But German colliery owners have for a long time recognised that for certain coals it is a distinct advantage to reduce the run-of-the-mine, or even certain qualities of coal, to a uniform size. In this country the preparation of Anthracite coal for the various home and foreign markets is now a most important matter, and in many instances Nuts of

várious grades command a higher price than larger coal because of their greater calorific value. It therefore often pays the coal owner to break large coal and to convert it into different grades of Cobbles, Nuts, Peas and Small. Apart from this, the utility of breaking certain classes of coal, as we have already pointed out, in order more readily

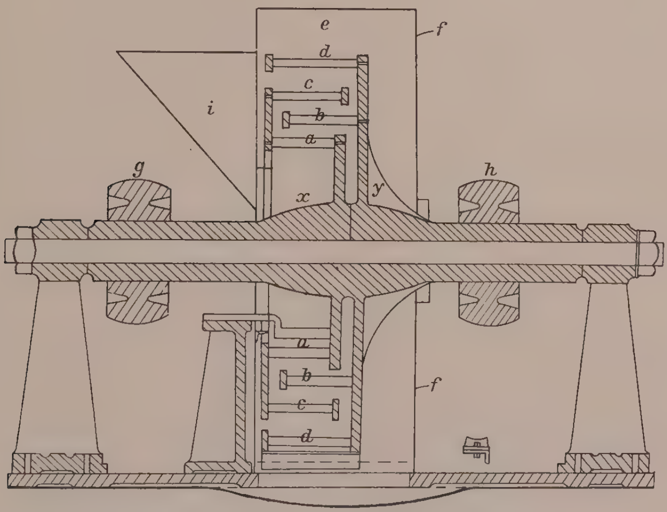


FIG. 34.—Coal disintegrator or crusher for reducing coal to uniform size.

to separate the inferior from the good qualities, will be easily recognised, in fact, there are many coals which could not be sold if they were not previously crushed so as to be capable of thorough washing.

In Fig. 34 is shown a machine for breaking the large lumps of coal to reduce them to a more convenient size or to make the extraction of the dirt contained in the coal a less difficult matter. It consists of two cylindrical cages

FIG. 35.—Ashington Colliery, showing pit heapstead, screening sheds, winding engine house, track and wagons.

By kind permission of Messrs. Head, Wrightson & Co., Stockton.

revolving in opposite directions, each cage being made up of two concentric sets of bars attached to a disc on one side and to a ring on the other. The coal to be broken is fed

into the centre, and is thrown by the bars *a a* of the cage *X* against the bars *b b* of the cage *Y*, thence it flies against the outer circle of bars *c* of *X* and finally against the outer circle of bars *d* of the cage *Y*. It then enters the circumferential space *e*, from whence it is allowed to escape by a suitable opening in the outer casing.

Screening and picking belts may be of various forms. The most common are made of woven wire cloth or perforated sheet metal if they are to be used as screens, and of whole sheet metal if to be used merely for picking. They are generally flat, endless belts, passing over a driving roller at one end and a second guiding roller at the opposite end. Conveyors are also used as screening and picking belts and possess great advantages as separators and classifiers of coals. Ordinarily, conveyors are used in the screens to carry coal from beneath the screen bars to the point at which it is to be picked or still further divided, and conveyor belts used for this purpose are shown in Figs. 30, 36, 37. Another form of conveyor consists of an indiarubber or canvas band supported on small rollers and driven by an end drum. In another form of conveyor a trough is used supported on live rollers which receive a peculiar "to and fro" motion from a patent driving mechanism. The effect of this motion is to cause the coal to be rapidly conveyed along the trough. By inserting perforated plates in the bottom of the trough these conveyors can be used as screening and picking belts. Another means of conveying coal, while at the same time obtaining good classification, as it allows the coal to be more easily picked, is one in which a metal trough with perforated sections at various points receives a

"backwards and forwards" throw by a reciprocating movement. This throws the coal gradually forward in easy stages. In another method of picking now being largely adopted an annular steel plate or table revolves horizontally on rollers. The coals from the shoot are delivered and

FIG. 36.—Plant constructed for the Cramlington Coal Co., Northumberland, and arranged to screen and pick 800 tons per day.

Reproduced by kind permission of Messrs. Head, Wrightson & Co., Ld., Stockton-on-Tees.

distributed evenly on this, after which they are picked by the pickers standing round the outer and inner circumferences. A scraper is arranged to remove the coals from the table, sliding vertically in guides. By this means the coal is directed into a shoot and thence into the waggons.

Elevators for lifting large quantities of coal from the screens, shoots, or other places into washeries, ovens, etc., are often required. A good example of these is one which is constructed of steel angles, framed together

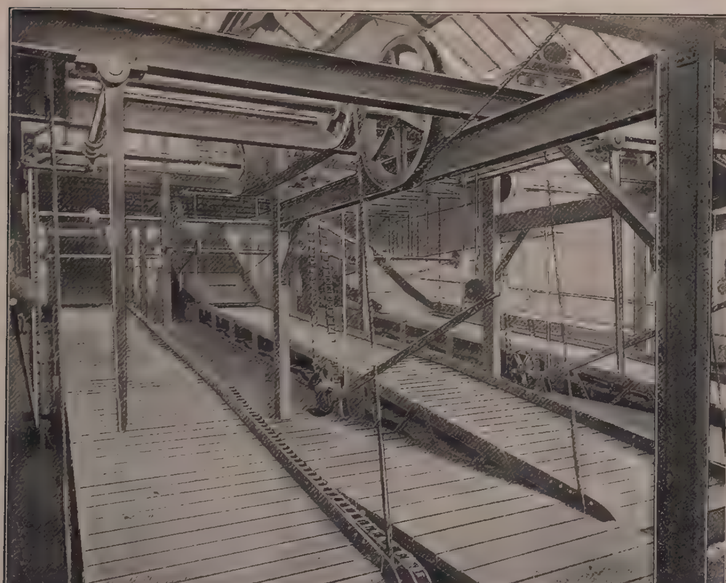


FIG. 37.—Interior of picking and screening shed, Universal Colliery, South Wales.

Reproduced by kind permission of Messrs. Head, Wrightson & Co., Ld., Stockton-on-Tees.

as shown, provided at the lower end with a boot. This has sliding blocks arranged to be moved up and down to keep the chains tight. In this way large quantities of coal or slack can be constantly raised almost any height, and at speeds up to 70 feet per minute.

Lowering Jib.—Fig. 38 shows another arrangement for

lowering the coal into the waggons and for conveying the slack away by means of a spiral conveyor. The travelling shoot, or lowering jib, consists of a self-contained lattice girder frame, hinged at the top and left free at the bottom, and it can be operated by either hand-power or power-

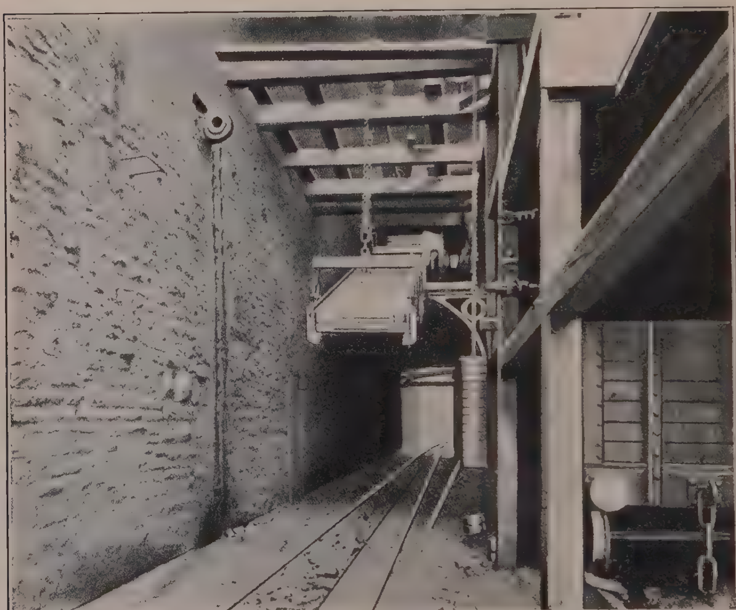


FIG. 38.—Lowering jib for depositing coal in waggons with minimum of breakage.

Reproduced by kind permission of Messrs. Heenan and Froude, Birmingham.

driven arrangement working the worm-hoisting gear, which enables the jib to be easily fixed at any height desired. The belt plates are of a peculiar corrugated section, giving strength and lightness, and the corrugations also prevent the coal from running down the shoot when placed at a

steep angle. By this arrangement tender coal can be lowered into the waggons without breakage and the better topping up of the waggons is facilitated, as the jib not only conveys coal right to the bottom of the waggon, but it will at the same time load well up over the top of the highest waggons in use.

Spiral conveyors are also largely used, not only in the screens, but for carrying the small coal to the washeries, boilers, or waggons. They have the great advantage of being simple in action as well as in construction, and need little attention and repairs when once installed.

Coal Washing.—Considering that many rare minerals of great intrinsic value are abstracted from large quantities of worthless gangue, it would be strange if the colliery engineer had not devised some means for removing from the coal the small quantities of dirt associated with it. German coal seams, as is well known, contain many bands of dirt or inferior coal, which in the process of working and transmission becomes mixed with the coal. This foreign matter can only be got rid of by elaborate washing arrangements, but the colliery owners of Germany have been so successful in their efforts to accomplish this, so as to increase the value of unclean coal, that British coal owners have imitated their efforts, not only for classes of coal which were of little value unless thoroughly washed, but even for the best seams, where it was found that the price increased as the percentage of dirt was reduced. It is clear that all inorganic material in the coal is worthless from the point of view of the calorific or heating power of the coal, and classes containing a large proportion of shale or sulphur have low heating powers. Many washers are capable of reducing the

shale from 20 per cent. to say 6 or 8 per cent. Of course it is easier to do this than to reduce say the 5 or 6 per cent. present in a good coal to 2 or 3 per cent., though this is now accomplished in many cases. Ordinary shale is not difficult to get rid of, but coal containing sulphur in certain forms needs more careful treatment.

When sulphur occurs in the form of pyrites it may be removed by washing unless the particles are so small as to be in the form of fine dust. For this reason it is essential that coal which is to be washed should not be broken up unnecessarily. At the same time it is necessary that the disintegration shall be complete enough to break the particles of foreign matter from the particles of coal. When the sulphur occurs as calcium sulphate it is most difficult to separate by preliminary treatment, and when it occurs in the form of hydrogen-sulphide it is generally only got rid of during coking.

The principle involved in nearly all coal washers is the same. Their action is based on the fact that in nearly all cases the impurities combined with the small coal, as it leaves the mine, are of greater specific gravity than the pure coal. This circumstance has enabled mechanical means to be employed which would not otherwise be possible. It is found that if materials of different specific gravities and approximately of the same size are placed in a sieve and jigged up and down in water for sufficient time, they will arrange themselves in layers according to their density, the heaviest at the bottom and so on. Or the machine may be constructed with a fixed sieve on which the coal to be treated is deposited and motion given to the water by means of a large piston, in this case motion is given to the water

instead of to the sieve with similar effect. A piece of mineral with a specific gravity of 6 falls through the water more quickly than a similar piece of some other mineral the density of which is only 2; but a large piece of the latter mineral may sink as rapidly as a small piece of the former. Consequently minerals of varying density can only be separated by water when they are properly classified as to size; they need not always be of the same size, but it is necessary that they shall not gain as much in size as they lose in density. It is true that in the early part of the fall of equal falling minerals, the influence of the specific gravity predominates, so that by a constant repetition of very slight falls, it is possible to separate particles which have not been carefully sized. On the whole, however, it is found best to classify the coals before washing, and almost all washers are arranged for this method, as it is found that with coals screened into nearly the same sizes, each size being treated separately and the conditions arranged to suit the sizes, viz., the number and length of the pulsations of the water, a more perfect separation is effected. It has already been pointed out that there is a danger in the reduction of the particles to too great a degree of fineness, so that the greatest skill of the colliery engineer is required to determine the most suitable size to which the coal may be reduced without the danger of creating too large a quantity of dust.

It is also found that by the introduction amongst the coal, of a mineral having a specific gravity slightly less than the heavier dirt particles and slightly greater than the coal, a more perfect separation is obtained. This mineral acts as a kind of filter through which the shale will pass and on the top of which the coal will remain. Felspar is an

excellent mineral for this purpose and suitable particles of this substance are placed in the sieves of the jiggers, as this class of washers is called.

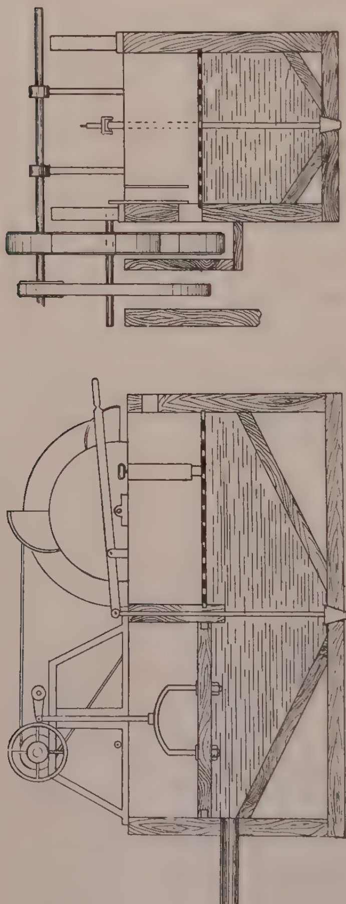


FIG. 39.—Jigger washer.

After the dirt has fallen through the sieve it is run off by the water to settling tanks, and the water when cleared or clarified is brought back again for further washing purposes. The washed coal is meanwhile led off to suitable hoppers, where the water is allowed to drain off gradually.

Coal may also be washed in troughs or on tables. In each case the action is based on the varying specific gravities of coal and dirt.

Fig. 39 shows a common form of jigger. This consists of a box or vat divided into two compartments by a partial partition. A flat sieve is fixed in one, which carries the coal to be washed, while in the other a piston works up and down, operated by an

eccentric above. As the box is full of water the movement of the piston causes a pulsation of the water lifting the coal up and down continually until gradually the arrangement of the particles in the mass changes, the heavier pieces being at the bottom, the light material at the top, and the mixed stuff in the middle. Thus, provided the box is not overloaded, a supply of unwashed coal can be continually fed on to the sieve from a hopper at one end, the dirt led off to the settling tanks from below as it filters through, and the coal directed to the storage bunkers to dry.

Trough Washers.—Some washers may be said to be travelling troughs, others are revolving troughs. The latter consist of an iron barrel which is about 8 or 10 yards long and about 4 feet in diameter, with an Archimedean screw on the inner surface. Friction rollers applied to the outer surface cause the barrel to revolve, the rollers being driven by a small steam engine

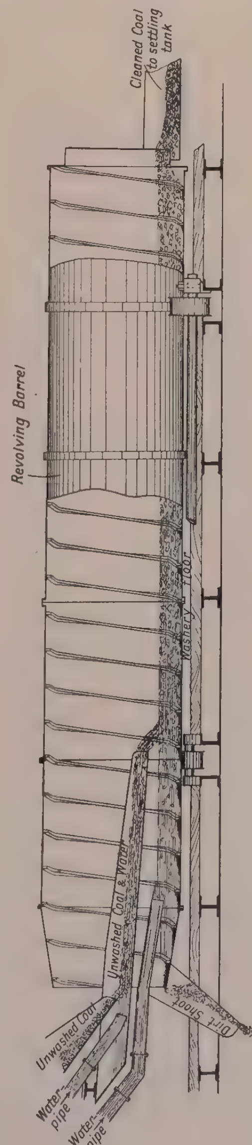


FIG. 40.—Blackett's revolving trough coal washer.

or electric motor. The coal enters the barrel about one-third from the upper end, and a stream of water joins it and carries it down a chute into the barrel. The point at which this unwashed coal enters is regulated according to the amount of washing it requires. A second stream of water operates at the point where the first stream and the coal enter the barrel. The coal is carried onward by this second current to the outer end of the barrel, but the dirt falls downwards into the thread of the screw on the inside of the barrel. The rotation of the barrel is in such a direction that anything falling into it is carried backwards and upwards to the end of the barrel, so that the dirt is gradually conveyed to the dirt hopper. In this way the coal is separated from the dirt, and each is delivered at its proper end into trucks in the simplest manner possible. Barrels of the size named will deal with from 100 to 150 tons per day, so that for large outputs several barrels are needed, but this is no drawback, as machines can be worked or stopped according as it is desired to turn out a larger or smaller quantity.

Washing Tables.—A table for washing coal is similar in many respects to the tables used in the concentration of ores. Like the trough washer, they are much simpler in construction and cheaper in first cost than jiggers—though it is possible that the cost of attention is much greater in the former types of washers. They are suitable for washing coal up to $1\frac{1}{2}$ inches diameter, so that larger coal must be first crushed; below the size named, however, it is necessary to classify the various sizes first, as table washers work better where the finer stuff can form a bed on which the larger may be gradually worked forward.

Tables have a capacity of about 7 tons of washed coal per hour, so that a large number are required for dealing with 400 or 500 tons of coal per day.

Drying the Coal.—The drying of the coal after washing is an important operation, as, although the moisture in the coal compensates somewhat for the loss of weight, consequent upon the abstraction of the dirt, the calorific power is reduced through the presence of water. In most cases the mere storing of the coal in hoppers from which the water can run off is considered sufficient. Hoppers are arranged in series, the partition of one being slightly higher than the next, by about a foot or ten inches. The water carrying the washed coal runs into the first hopper until the coal gradually fills up to the top, whereupon the water overflows into the next hopper, carrying with it a further supply of coal, and so on until the whole of the hoppers are filled. Meanwhile the wet coal is draining itself through slight openings in the timbers of the hopper. The coal is afterwards shot through trap doors in the bottom of the hoppers into waggons. But in order to more thoroughly dry the coal, special arrangements are adopted.

The most important feature of the "Baum" system, for example, is the draining plant (Fig. 41), which is designed to reduce the added moisture in the coal as much as possible. At the same time the water is clarified, and the greater part of the slurry extracted by filtration through a constantly renewed layer of fine coal. A draining plant consists of an extremely strong conveyor, carrying about 2 tons of coal to the yard. This is made with perforated plates, *a* (Fig. 41), hinged one to the other, and carrying on the

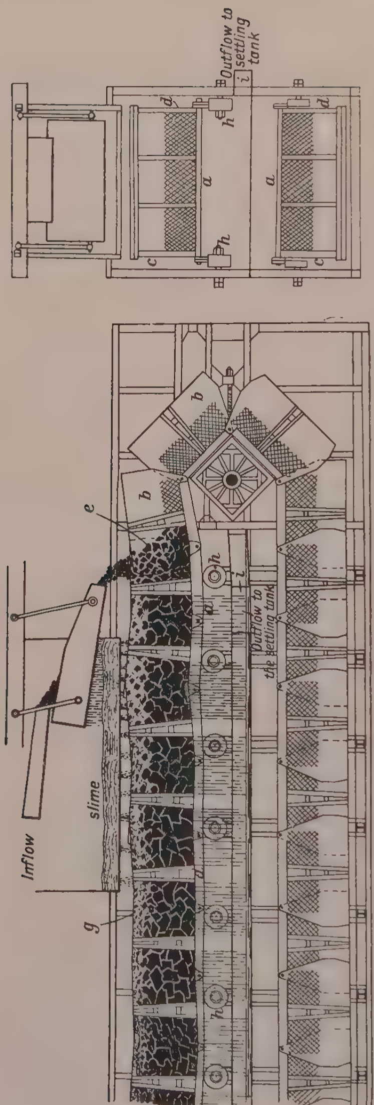


FIG. 41.—Mode of drying coal after washing.

middle a double vertical partition *b* of perforated sheets, set slightly apart from each other to allow the water to run between them and two upright sides *c* and *d* also perforated. The conveyor thus resembles a series of boxes hinged one to another. The washing water comes with the fine coal on specially arranged swinging sieves of metallic gauze, which allows the water, the slurry, and the very fine coal to pass through, whilst the coarser coal slides down to the conveyor at *e*. The finer coal and the slurry, separated as just mentioned, then fall on to the top of the coarser coal. The coal is now in the best condition for draining. As the conveyor moves it passes over

the supporting rollers *h*, the distances and the differences of height between which are calculated, so as to allow the conveyor to bend under its load of coal between one roller and the next. The effect of this sagging of the conveyor is to press the coal between the vertical partitions *b* when it arrives between the rollers or above the lower rollers, and to open these partitions one from the other as it arrives above the higher rollers. The coal is in this way submitted to a process of pressure and expansion, which forces the water from it. It will be seen that as the washer proper is situated at the top of the buildings, the coal passes from it downwards, and thus the processes of washing, screening, draining, storing, and loading are carried through without the necessity of repeated liftings with elevators, and consequently with less formation of small coal and with a minimum of manipulation.

Cost of Washing.—The cost of washing coal varies from about 2*d.* to 4*d.* per ton, including driving and maintenance, though in some cases, where little sizing is necessary and the dirt is not greatly intergrown with the coal, the cost may be less than 1*d.* per ton. On the other hand, coal is enhanced in value as much as 6*d.* or 7*d.* per ton by washing, and as the demands of the trade are in all cases for a cleaner product, it is evident that the washing of coal is an advantage to both producer and consumer. It will be seen, also, that the selection of a suitable washing plant needs serious consideration.

Loading Coal into Ships and Barges.—The loading of the coal into waggons, ships, or barges is the final operation in the handling of coal, so far as the colliery owner is concerned. It is just as necessary that care should be

taken in doing this, so as to avoid loss and breakage of coal, as in the case of the withdrawing of the loaded tubs from the cage and the ejectment of the coal on to the screens. We have already referred to the lowering jibs which enable coal to be passed easily from the screening belts to the waggons; it is now only necessary to describe a method of loading it into the ships.

Coal is loaded into ships and barges from the waggons in various ways:—(1) By means of large cranes which raise the entire waggon, or sections of specially-made waggons, over the hold of the ship, the contents being emptied through a trap-door in the under-side. (2.) By means of elevators which raise the coal to a certain height above the vessel, after which it slides down by means of gravity through a shoot into the hold. (3.) By means of specially-designed coal shippers.

Mechanical coal shippers are designed so as to avoid the great breakage of coal resulting from the use of the ordinary gravitation spout. The motion of the coal from the truck on the dock side to the bottom of the hold of the vessel is caused to be independent of gravity, and to be entirely controlled by machine-driven belts. With a continuous supply of coal, 400 tons per hour can easily be shipped by these appliances, and this can be increased by a slight increase in the speed of the belts and the capacity of the trays. The coal is first discharged into a hopper immediately below the truck. The first belt, which is horizontal or slightly inclined, moves under the mouth of the hopper, and draws a layer of coal along its surface until it arrives at the side of the quay. At this point it is transferred to the second or jib belt. The frame carrying the second

belt is hinged at the shore end, so that it can rise and fall at its outer end to suit the rise and fall of the ship, and has also a slewing motion, right and left, to enable the coal to be directed along it towards any part of the hatch, in order to save hand-trimming. At the end of the jib a vertical belt is usually suspended, which moves in a trunk. This belt has large trays working freely on hinges. These, in turning round the top drum, form a series of large hoppers, or scuttles, the sides of which are the sides of the stationary trunk, and the bottoms of which are the descending trays. As each hinged tray arrives at the bottom of the trunk it falls open automatically, and discharges its contents on the cone of coal forming gradually in the hold. The tray is then carried round the bottom roller of the belt in a vertical position, and rises on the outer side of the trunk, until it arrives again at the top roller, when it is automatically turned over, and again receives the coal in the hopper which it forms with the sides of the trunk. By this means a series of huge scuttles is formed automatically, in which the coal quickly descends into the vessel, helped by the force of gravity, but entirely controlled by the machinery. By a suitable arrangement of railway sidings and hoppers, several machines can be arranged, so that all the holds in a vessel can be supplied at the same time, thus obtaining extreme rapidity of despatch for vessels. In this case the machines are made to move parallel to the quay and to the lines of railway, so as to plumb any position of hatchway.

Sufficient has now been written to show that the preparation of coal for the consumer is not the least important branch of colliery work, and that great skill

has been shown in devising methods and appliances for ridding the product of the mine of everything tending to lower its economic value.

The aim of the colliery engineer is to render it most useful and convenient for domestic purposes, and for those processes of iron and steel making and steam generation for which it is now so greatly required. In this purpose he is largely helped by those German engineers who have for so long been engaged in devising plant for the treatment of fuel, for although modern British engineering has been able to do a great deal for the mine owner in the direction of motive power, especially in the new forms of electrical installations, it is to his Continental friends that he and the consumers are chiefly indebted for a thoroughly clean and adequately sized coal, and for the means of freeing it from the greater part of its undesirable constituents.

This complete utilisation of the coal has another important advantage: it avoids waste of the product in the form of dust and smoke, so common at collieries where no effort is made to avoid them. Nothing strikes a British mining engineer so forcibly, on visiting the best German mines, as the quiet and cleanliness which prevail at the surface. Nothing is wasted; the smoke from the ovens and chimneys is conspicuous by its absence, the air is clear and unpolluted, and fields of grain and gardens of vegetables grow up to the very walls of the coking plants.

Coking Coal and the Recovery of Bye-products.—Recent improvements in the method of coking coal and in the recovery of valuable bye-products have caused great attention to be paid by colliery owners to this branch of the industry. The simple manufacture of coke, even from

those varieties of coal possessing excellent coking qualities, was not considered remunerative except in a very few instances, *e.g.*, in the case of those collieries worked in conjunction with iron and steel manufacture—and consequently the supply of coke to a great extent was in the hands of the makers of coal gas for illuminating purposes.

The chief improvements have been in respect of the retorts or ovens. These are now of greater capacity and capable of a more varied output. Ordinary gas retorts were generally built for holding three or four cwts. of coal and for coking this quantity in three or four hours. More than as many tons are now filled into modern retorts and a period of twenty-four hours is required to completely carbonise the larger charges. Under the new methods a higher quality of coke is obtained, and for blast furnace purposes this is more valuable than gas works coke. In addition to this the bye-products are generally of better quality, and are given off in larger quantities. Coke made in ovens of this kind for blast furnace use, called *Furnace Coke*, is, on account of the larger charges and peculiar construction of the ovens, much larger in bulk and considerably harder than the older form of coke. Being stronger it is therefore more suitable for supporting the metal in the blast furnace and allows a more efficient current of air to pass through than is possible with a softer quality.

The coke obtained in the manufacture of illuminating gas—*Town Gas Coke*—is smaller and softer than that described. Usually it is the residue of a better quality of coal than that used in modern coke ovens, the best coal for the production of gas of a high candle power being generally employed, and although the coke is of a soft nature owing

to the shorter time during which the process of carbonisation is proceeding, it is eminently suited for domestic or blacksmith's purposes where open grates are available. Again, the percentage of ash in this variety of coke may be low, say from 5 to 7, and of sulphur about 1 per cent., whereas in the case of small coal used on a large scale for the production of coke in ovens, the ash and sulphur present in the resulting coke may be as much as 10 to 12 per cent. Considerable heat therefore may be expected from the former in almost all cases.

On the other hand, furnace coke may be superior for domestic purposes where closed stoves are employed (as in the United States and other countries). In this case a good draught is available, and as it is necessary to avoid the massing together of the lumps, the stronger coke is more suitable than the softer qualities. Apart from the advantages possessed by coke for the definite purposes which have already been named, it is now being clearly recognised that by the conversion of the raw coal into a smokeless fuel by carbonisation a great amount of heat is saved and the atmosphere of large cities is not darkened and begrimed by clouds of smoke and soot, which is such a common feature of British industrial centres. It is remarkable that the demand for smokeless fuels in this country is not greater at the present time than is actually the case. Many British fuels are particularly suitable for coking, the recovery of valuable bye-products and the efficient utilisation of the gases would be a great economic gain to the whole nation; finally, there are now many greatly improved methods of coke manufacture and bye-products recovery. It is possible, therefore, that during

the next few years a great change will take place in this part of colliery work whereby the title of coal mining district will not be associated in future with localities devoid of all natural beauties.

In the manufacture of gas by ordinary retorts it is often necessary to consume some portion of the coke produced, on the fire bars. That is to say, the heat required to completely carbonise the coal is so great that the coke supplies are called upon to provide some of it. In modern coke ovens the heat necessary to produce good coke can be obtained without using any of the coke itself, some of the resulting gas being made use of instead. This is done without reducing the value or the quantity of the bye-products. These can be collected without affecting the quality of the coke, as it is only necessary to keep up the heat so as to produce good coke after the tar and ammonia have been removed.

As a rule a suitable coal should produce 9,000 to 12,000 cubic feet of gas, and seven or eight cwts. of coke, per ton. In a modern oven about half of the gas is employed for heating purposes and the remainder is available for illuminating or power purposes. Loss of gas and bye-products and the production of an inferior quality of coke is a serious drawback in any plant, and the use of retorts of ordinary construction, although saving all the gas for illuminating purposes, has not resulted in the complete saving of the bye-products nor in economy in fuel.

Coking, with the recovery of Bye-Products.—In most cases coke ovens are built in such a way that they can be used either for or without the recovery of bye-products, though in a few instances it is necessary to have a plant of entirely

FIG. 42.—Coke ovens with bye-product recovery.
By kind permission of the Otto-Hilgenstock Coke Oven Co.

different construction if the products are to be saved. There are now many methods employed, most of which are of German design, but the main feature in all of them is the same, viz., that the coal is carbonised or coked by the hot gases which circulate outside the retorts, these gases being produced from the coal itself.

The small coal to be coked is first compressed and then pushed into the retorts. The products evolved when the coal distils are passed through scrubbers and condensers, by means of which the various tars, oils, and ammoniacal compounds are separated. Deprived of these valuable constituents, the

gases return to the outside of the ovens around which they circulate and are burnt, along with heated air, finally passing under the steam boilers where they are still further used. In most cases the ovens are so constructed that the temperature is not high enough to decompose the light oils contained in the gas escaping from the ovens, and as a rule they are so arranged that the heat is regular and uniform in all parts of the oven, the draught being shut off either at the front or back of the retorts, as required.

Many large installations are now at work, especially in Yorkshire, South Wales, and Scotland, for the manufacture of metallurgical, railway, and domestic coke, quantities of which, however, are shipped to America especially for the latter purpose. The plants erected are similar in principle and the following description of an Otto-Hilgenstock battery of ovens may be taken as typical of the remainder of the plants built for this purpose.

The improved Otto-Hilgenstock system is based on the principle of the widest possible distribution of gas through the shortest course. The principal feature of the system is that the ovens are bottom fired, that is to say, they are heated from below by means of the combustion of gas in a number of Bunsen burners. The process is as follows:— The gases evolved from the coal in the oven chamber *A* first pass through the opening *B* into the gas main *C* on the top of the ovens, from whence they are drawn into the gas coolers and other bye-product recovery apparatus by means of steam-jet gas exhausters. The gas freed from the bye-products and that for heating the flues of the ovens, return through the main pipe *D* which feeds all the different ovens of a battery. From this main gas pipe smaller pipes *E*

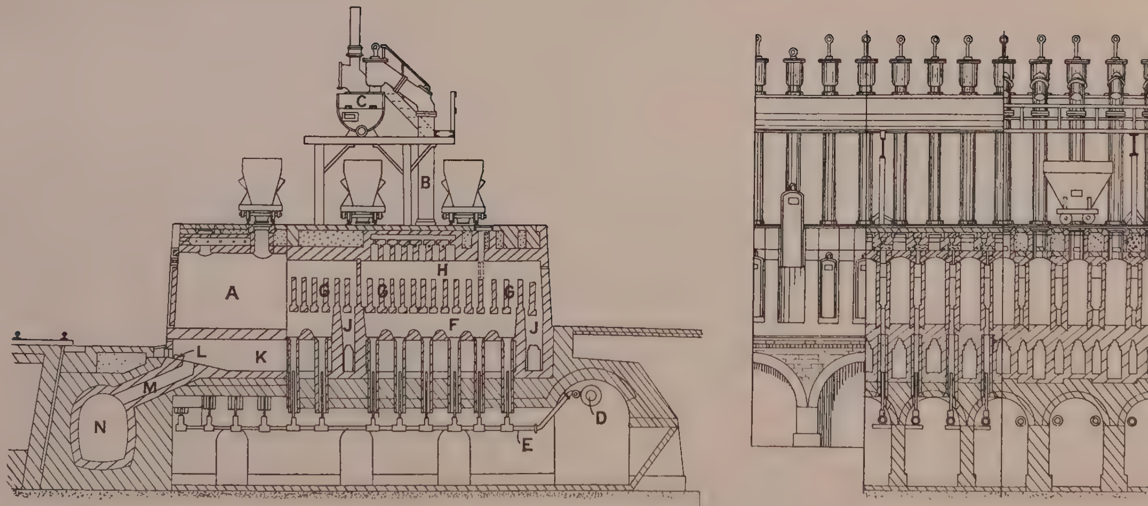


FIG. 43.—Coke ovens with bye-product recovery.

branch out and go into the arches which support the ovens, as may be seen in the annexed drawing (Fig. 43). From these branches *E* are led lateral branches rising to nozzles inserted in the heating flues *F* of the chambers which convey the necessary gas to each wall. The Bunsen burners draw in by their action sufficient air for complete combustion. Owing to this action the air is heated on its way from the arches supporting the ovens into the heating flues. Furthermore, the air, as well as the gas, in fact, the mixture of gas and air, is heated on its way alongside the "sole flue" to the combustion channel *F* by the heat of the waste gases flowing through the "sole flue" which acts as a recuperator.

Thus, in a simple way, and without complicating the working of the ovens by any special pre-heating apparatus, a great part of the heat contained in the waste gases is transferred to air and gas before reaching the combustion channel *F*. The flame ignites at the level of the coking chamber, and rises vertically to the horizontal top flue *H* through the heating flues *G*. The direction of the flame throughout is a natural one, upwards, by reason of its own buoyancy and not on account of chimney draught. From this horizontal top flue, divided into two halves, the burnt gases are led off through the vertical flues *J* under the bottom *K* of the oven, generally known as the "sole flue." The burnt or waste gases pass through the "sole flue," pre-heating the air and gas on the way to the combustion chamber as described, and finally are drawn through the opening *M*, which can be regulated by the damper plate *L*, to the main waste gas collector *N*. Thus the waste gases pass into a boiler plant where the

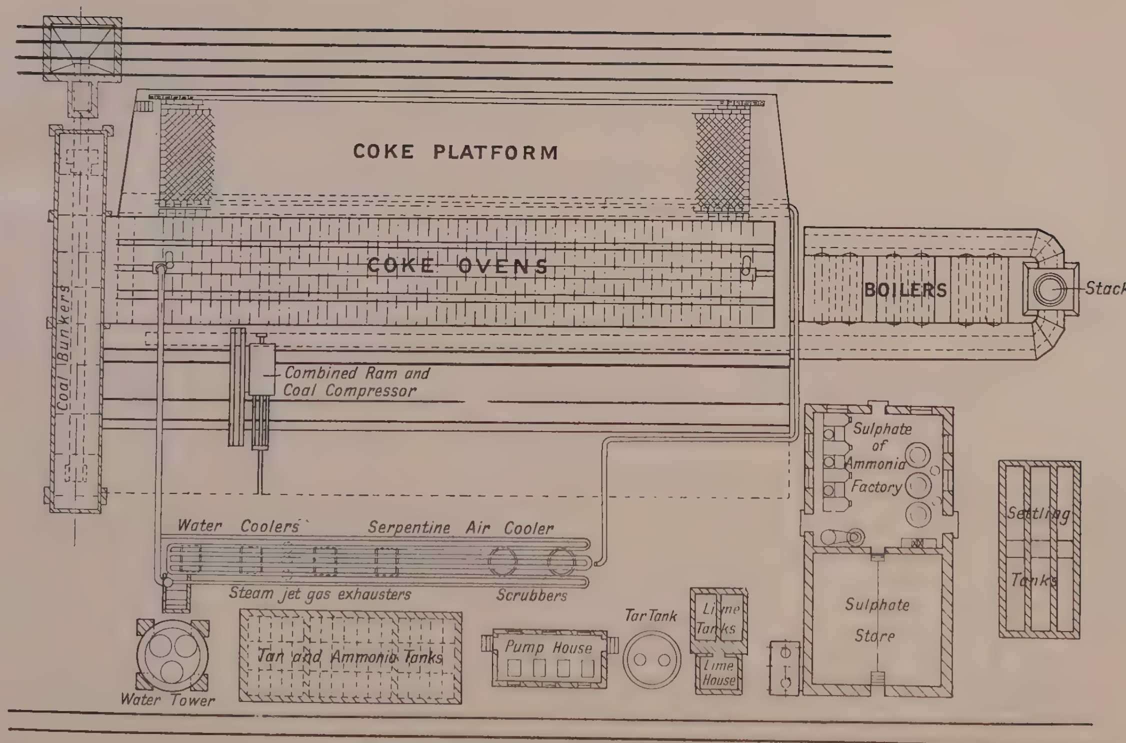


FIG. 44.—Coke ovens with bye-product recovery.

rest of the heat still contained in them is used for raising steam, and ultimately are drawn off by the chimney stack.

Fig. 44 shows a complete plant of sixty bye-product ovens, with coal bunker, coal stamping machine, and recovery plant for tar and ammonia, and for converting the latter into sulphate of ammonia.

The cycle of operations in the recovery plant is as follows :—

The gases evolved during the process of coking are drawn off from the gas collecting main, on the top of the ovens, through an upwardly inclined serpentine air cooler, and then through water coolers. The gases thus cooled down to about 20° C. (68° F.) are freed from ammonia, and if necessary from benzol, etc., by passing through

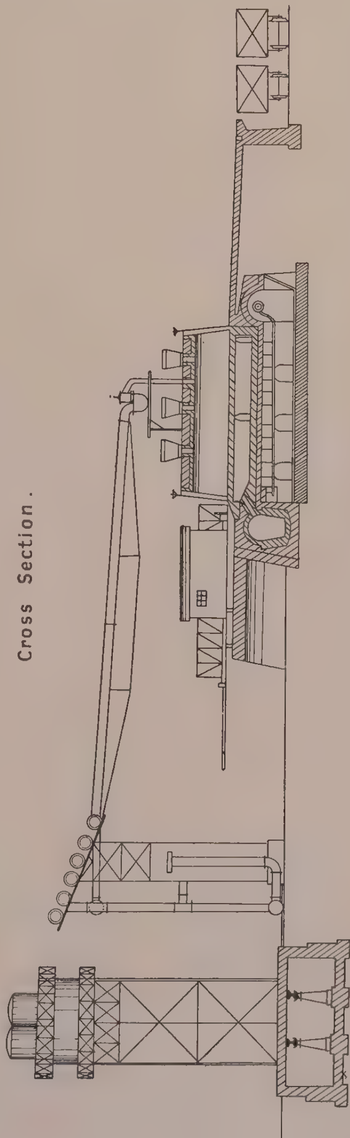


FIG. 45.—Coke ovens with bye-product recovery.

scrubbers, and are then led back to the ovens to be used, a portion for heating the ovens, and the surplus for such purposes as may be desired. The necessary suction and pressure are brought about by means of steam injectors which are placed between the water coolers.

The object of the upwardly inclined serpentine cooler is to facilitate the separation of the distillates from the gases. The highest point of the serpentine cooler, where the return flow commences, is chosen to coincide with the point at which the condensation gases have been cooled to about 70° C. (158° F.). The returning distillates are again partly evaporated by meeting the hot gases coming in the opposite direction, the evaporation being the greater the nearer the distillates approach the gas collecting main. Consequently, the light oils in the tar, the volatile ammonia in the ammoniacal liquor, and a fresh supply of water vapours are in this way conveyed into the water-coolers.

That part of the ammoniacal liquor which returns through the serpentine cooler without being again evaporated only contains fixed salts, and, therefore, after being drawn off and cooled, may be used in the washers, instead of fresh water.

The reciprocal action between the incoming gases and the returning distillates washes or lixiviates the fixed ammonia, which so easily sticks to the tar condensing near the gas main.

As already stated, the gases on leaving the serpentine air cooler are impregnated with water vapours, and being condensed by the effective cooling in the water coolers, produce a rich ammoniacal liquor. A further enrichment

of the ammoniacal liquor is effected by means of steam injectors, which operate in a three-fold manner. In addition to its power of suction, the steam introduced by the injector into the cooled gas forms a very rich ammoniacal liquor, condensing in the water coolers, which are placed immediately after the injectors. Lastly, by the active power of the steam and its thorough intermixture with the gases, a most effective separation of the final particles of tar is arrived at.

For charging and discharging coke ovens in modern installations, the coal is fed through a stamping machine by means of which it is made into a cake and is then carried bodily by mechanical means right into the oven. By means of this compression and accurate charging a larger quantity of coal can be coked and a denser product obtained. When distillation is complete the mass of coke is ejected by the same mechanical means. This mechanical charging apparatus consists of an iron box or compressing chamber of the same internal dimensions as the coking chamber, and having a moving sole actuated by a rack and pinion motion. When the small moist coal has been run into the chamber from the bunkers, the stamp is operated and the coal is compressed into a cake. This is then carried into the oven by the sole. When the oven door is closed the cake is retained and the sole may be withdrawn, suitable provision being made at the bottom of the door to permit of the withdrawal. The coking of the prepared coal then begins, and on the completion of the process the mass of coke may be readily forced out, the intense heat and the construction of the ovens enabling the whole operation to be done in a comparatively short space of time.

Briquettes.—Many qualities of small coal which are unsuitable for making into coke have latterly been formed into Briquettes or Patent Fuel, and in this way coal which was formerly wasted is turned to good use. When treated in a certain way, presently to be described, and formed into suitable rectangular or oval blocks, this small, sometimes inferior, coal becomes of great value for heat generating purposes, has the advantage of being unaffected by the weather, and is in a most convenient form for storing and handling.

The coal is first screened, and, if necessary, washed, dried, and crushed, before being formed into blocks. Neither large nor extremely small and dusty coal is necessarily the best for briquette manufacture, there being a medium size which is found most convenient. The chief materials used for binding are pitch, starch, and lime. Pitch has three advantages: (*a*) it assists in the combustion of the coal; (*b*) it adds very little ash; (*c*) briquettes formed in this way are very hard and proof against water and weather. Pitch is produced from the distillation of gas-tar, and when coal is used instead of coke for iron smelting, is one of the bye-products. The most suitable quality is that containing 75 to 80 per cent. of carbon. An illustration of a briquette machine is given in Fig. 46. The pitch is first broken by means of a disintegrator or "cracker," and is then fed, along with the coal, into a mixer, where both constituents are accurately measured. Both then pass into a disintegrator, where they are ground together to a proper degree of fineness. The mixed material is then elevated and delivered into a vertical heater, and as it passes downwards is subjected to the

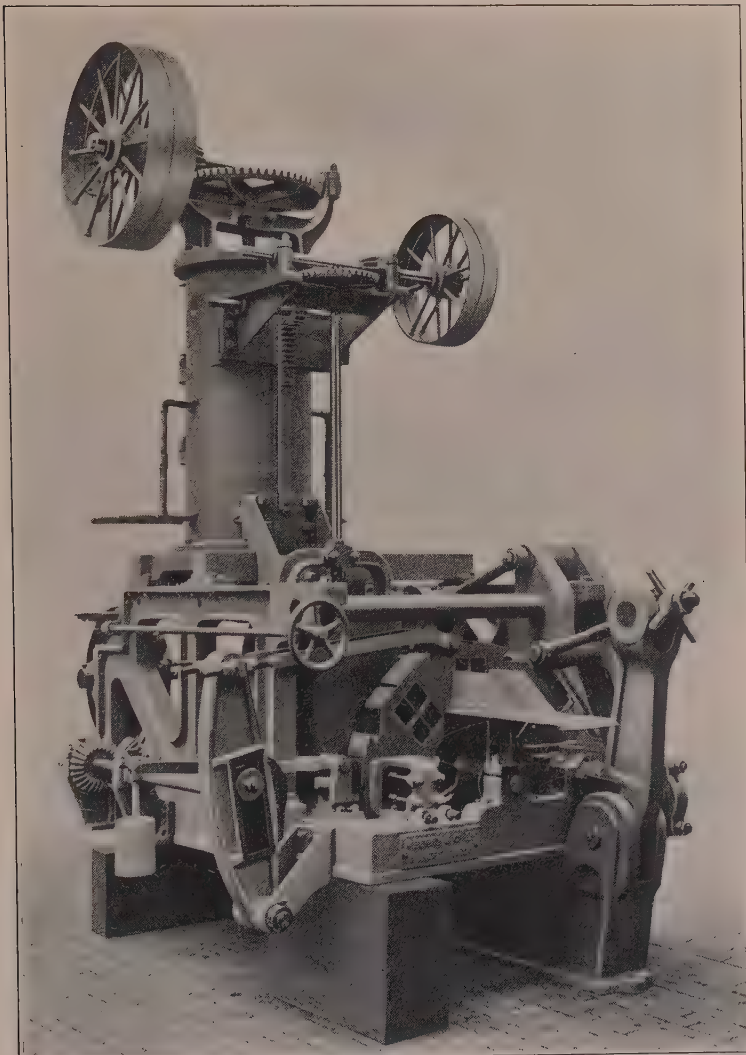


FIG. 46.—Yeadon Briquette machine.

action of superheated steam, by means of which the pitch becomes plastic and adhesive. The briquette press is immediately below the heater and is fitted with a vertical mould plate containing a number of moulds. At each stroke of the machine the plastic material is pushed by a horizontal ram into one of the moulds. On reaching the opposite side, the full mould is powerfully compressed from both sides simultaneously by two horizontal rams. A fourth ram pushes out the finished compressed blocks which are then taken on a band conveyor to the stacking ground or loaded into waggons.

A briquette machine is usually capable of turning out from 100 to 250 tons of briquettes per day. The briquettes produced vary in size from 2 lbs. and 3 lbs. for domestic purposes up to 22 lbs. for marine purposes, the most common size being 2 to 3 lbs. for domestic, 6 to 8 lbs. for locomotives, and 12 to 16 lbs. for marine uses.

Briquettes made with pitch probably have greater calorific value, are cleaner and less smoky than those made in any other manner, but in general practice a certain amount of the other binding agents is used with it. Starch mixed with lime is found to be a good means of binding, and, although a rather large percentage of ash is left after burning, the heat generated is usually high, the smoke given off is small, and the cost is considerably less than when formed with pitch.

CHAPTER XV.

COALING STATIONS OF THE WORLD.

At home, the coal supplies of this country have enabled England through her great and important industries to be pre-eminent in manufactures of every kind. This is not the extent, however, of the value of England's fuel resources. Abroad, her coal depôts mark the maritime coaling stations not only of her own ships but those of almost every other maritime power; and it is her ships that are employed to carry the valuable product to almost every country and seaport in the world. British coaling stations, British coal, British ships are essential for the very existence, not only of this country, but of most European countries and of many others in both hemispheres. Neither British nor foreign steamships, sailing either from the home ports, from Hamburg or the Baltic, from Dieppe, Bordeaux or Marseilles, can reach India, China or Japan without British coal. All great liners to the Orient must coal at Gibraltar, Port Said, Aden, Colombo, Singapore and Hong Kong, or if proceeding by another route, must stop at Cape Town or other South African ports for fuel.

British coaling stations are found in every part of the world. In the Mediterranean they are established at Gibraltar, Malta and Alexandria, and at almost every other port. British coal ships are found in every harbour of the Baltic and North Seas, and in the harbours along the

coasts of the Atlantic, the Pacific and the Indian Oceans. It is difficult to imagine what the condition of many peoples in the centres of civilisation on the earth would be like deprived of the coal which is sent to them from these islands; the traders, fillers, stokers and lightermen of San Francisco, Valparaiso, Zanzibar, and the coaling stations named; the workers in the manufactories of the Colonies, India, China, Japan and South America; the residents of the Azores, the Canary Islands, Madagascar and the West Indies. All these stations or anchorages have stores of the fuel which England supplies, and in so far as they are without this fuel are her dependents.

Coaling Stations of the British Isles.—At a large number of the ports of these islands steamers are enabled to take coal on board for their boilers, and ships of all descriptions may obtain outward freights at almost the same number of ports. The chief of these are:—Cardiff, Newport, Swansea, Barry, Milford Haven, Port Talbot, for the South Wales trade; Newcastle, North and South Shields, Sunderland, Wearmouth, Blyth, Hartlepool, Seaham, Tynemouth and Whitehaven for the Northumberland, Durham and Cumberland trade; Liverpool, Birkenhead, Hull, Holyhead and Fleetwood for the Lancashire, Yorkshire and North Wales coalfields; Glasgow, Ardrossan, Ayr, Dundee, Leith, Oban and Wigton for the Scottish trade; London, Bristol, Dartmouth, Exeter, Falmouth, Plymouth, Portsmouth, Southampton and Portland are important coaling stations, and outlets for coal from all the chief coal areas of England and Wales. In Ireland coal is stored or exported at or from Cork, Dublin, Belfast,

Limerick, Londonderry, Wexford and Yougal. Other stations in the British Isles are Grimsby, Whitby, Cowes, Longhope (Orkney), Scilly and Troon.

Mediterranean Ports.—Special facilities are not only provided at certain Mediterranean ports, but at many other foreign coaling stations, for the loading or unloading of coal to or from ships. As a rule, coal dischargers are capable of shipping from 100 to 200 tons per hour each from single ships. The chief coaling stations of the Mediterranean and adjacent thereto are—In **Spain**: Gibraltar Barcelona, Cadiz, Seville, and Huelva; in **France**: Cette, Marseilles, Toulon, Nice; in **Italy**: Genoa, Naples, Brindisi, Ancona, Venice, Savona, Bari, Gallipoli, and in the neighbouring isles, Messina, Augusta (Sicily), Ajaccio (Corsica), Cagliari (Sardinia), Malta (Valetta); in **Austria-Hungary**: Trieste, Fiume; on the **Black Sea** (**Russia, Roumania**, and **Bulgaria**): Odessa, Batoum, Galatz, Ibraila, Constantinople, Smyrna (Asiatic); in **Syria**: Beyrout; in **Greece**: Corfu (Ionian Isles), Piræus, Syra; in **Egypt**: Alexandria, Port Said, Suez; on the **North Coast of Africa**: Tunis, Algiers, Bizerta (Tunis), Bona (Algiers).

North Sea and English Channel Coaling Stations.—In **Holland**: Amsterdam, Dordrecht, Flushing, Rotterdam, Ymuiden, Zaandam; in **Belgium**; Antwerp, Ostend; in **Germany**: Bremen, Brake, Bremerhaven, Dantzig, Emden, Geestemunde, Hamburg, Kiel, Memel, Stettin, Wilhelmshaven; in **France**: Cherbourg, Havre, Honfleur, Boulogne, Caen, Calais, Dieppe, Dunkirk, St. Malo, Port Audemer, Nantes, Rouen, Trouville; in **Denmark**: Copenhagen, Elsinore; in **Norway and Sweden**: Christiania, Bergen, Christiansund, Dram, Trondhjem, Helsingborg.

Coaling Stations of the Baltic Sea.—In **Sweden**: Malmö, Carlscrona, Stockholm: in **Russia**: Revel, Riga, St. Petersburg, Abo, Cronstadt.

Coaling Stations of the Bay of Biscay and Portugal.—In **France**: Bordeaux, La Rochelle, Nantes: in **Spain**: Bilbao, Corunna, Vigo Bay; in **Portugal**: Lisbon.

Coaling Stations of the North Atlantic.—This portion of the world is more adequately provided with points at which steamers can ship fuel or other ships procure cargoes than any other portion of either hemisphere. In all there are 55 coaling stations, in addition to the Home Ports, already given, on the North Atlantic Seaboard, situated at the following places—In the **United States**: Baltimore, Boston, Charleston, Chester, Coosaw River, Galveston, Gulfport, Mobile, Marcus Hook, Newport News, New Orleans, New York, Norfolk, Pensacola, Philadelphia, Portland (Maine), Savannah; in **British North America**: Pictou (Nova Scotia), Quebec (Canada), St. John (New Brunswick), St. John's (Newfoundland), Halifax (Nova Scotia), Louisberg (Cape Breton), Sydney (Cape Breton), Yarmouth (Nova Scotia): in **Islands of the Atlantic**: Ascension, Bermudas (St. George's Harbour), Cape Verde, Curaçao (West Indies), Falkland Islands, Havana (Cuba), Fayal (Azores), Fernando Po (West Coast of Africa), Horn Island, Kingston (Jamaica), Lagos (West Coast of Africa), Las Palmas (Grand Canary), Funchal (Madeira), Nassau (New Providence, Bahamas), New Stanley (Falkland Isles), Jamestown (St. Helena), St. Lucia, St. Michael's (Azores), St. Thomas (West Indies), St. Vincent, Santa Cruz (Canary Islands), Ship Island and Trinidad; in **Africa**: Cape Coast Castle, Dix Cove (West Africa), Elmina (West Africa), Lagos

(West Africa), Cambia (West Africa), Loanda (West Africa), **Sierra Leone (West Africa).**

COALING STATIONS OF THE SOUTH ATLANTIC.—In **Africa:** Cape Town, Congo (West Africa), Mossamedes (West Africa), Simons Town (Cape Colony), Whydah; in **South America:** Bahia (Brazil), Bahia Blanca (Argentine Republic), Belize (British Honduras), Buenos Ayres (Argentine Republic), Ceara (Brazil), Monte Video (Uruguay), Natal (Rio Grande del Norte, Brazil), Para (Brazil), Pernambuco (Brazil), Punta Arenas (Straits of Magellan), Rio Janeiro (Brazil), Rosario (Argentine), Santos (Brazil), Vera Cruz (Mexico).

COALING STATIONS OF THE INDIAN OCEAN.—In **Arabia:** Aden; in **Persia;** Bushire; in **India;** Bombay, Calcutta, Coconada, Colombo (Ceylon), Kurachee, Madras, Moulmien, Trincomalee (Ceylon); in **Burmah** and the **Malay Archipelago:** Batavia (Java), Labuan (Borneo), Penang (Straits Settlements), Rangoon (Burmah), Singapore (Straits Settlements), Sourabaya (Java); in **Africa:** Beira (Mozambique), Delagoa Bay, Mombasa, and Zanzibar. There are also stations at Bourbon, Bunsorah (Turkey), Droketon, Galle, Karatzu, Kallindim, Mauritius, Muroran, Perim (Gulf of Aden), and Seychelles.

COALING STATIONS OF AUSTRALIA AND NEW ZEALAND.—In **Australia:** Adelaide (S. Australia), Albany (Western Australia), Hobart Town (Tasmania), Melbourne (Victoria), Newcastle (New South Wales), Perth (West Australia); in **New Zealand:** Auckland, Christchurch, Otago, Wellington.

COALING STATIONS OF THE PACIFIC.—On the seaboard of **North and South America:** Acapulco (Mexico), Asteria (United States), Caldera (Chili), Coronel (Chili), Esquimalt (British Columbia), Guayaquil, Ecquador, King George's

Sound, Lota (Chili), Mazatlan (Mexico), Naniamo (British Columbia), Vancouver (British Columbia), Portland (United States), Panama (Central America), Payta (Peru), San Diego (United States), San Francisco (United States), Seattle (United States), Tacoma (United States), Valparaiso (Chili), Victoria (British Columbia); on the **Asiatic Coast:** Amoy (China), Banghok (Siam), Canton (China), Hong Kong (China), Kobe (Japan), Moji (Japan), Nagasaki (Japan), Shanghai (China), Tamsui (Formosa), Yokahama (Japan); in various **Islands of the Pacific:** Honolulu (Hawaii), Manila (Philippine Islands), Fiji Islands, Tahati (Polynesia).

Conclusion.

The work of the coal miner is of supreme importance, and the same may be said of the skill of thousands of engineers who, quick to take advantage of the latest discoveries in science, have introduced the best life and labour-saving appliances into mines, and have utilised those forces of Nature which enable the mineral to be got from its bed in the earth's crust and to be transported in ships driven by wonderfully designed engines actuated by the heat derived from it, to remote countries and to strange peoples. This country has a great past upon which it can look back with pride, but the present position and the future possibilities are even more satisfactory. So long as her sources of coal are equal to the demands of her industries and those of lands across the seas, England will continue to be prosperous. Five hundred years may not suffice to exhaust the present supplies, but the period when this

country may need to purchase coal in foreign markets may be greatly lengthened by those engaged in getting and utilising the present available stores. Coal must not be wasted either in the mine or on the surface; more equal terms of leasing and improved methods of winning will avoid underground waste, and further discoveries and new machinery will enable greater power and increased products to be obtained from the fuel.

If he who makes two blades of grass grow where formerly one grew is a benefactor to mankind, surely he who gets two pounds of coal where formerly only one was obtainable, or who causes a fuel to yield double its former products or power, is no less a benefactor.

INDEX.

BRADBURY, AGNEW, & CO. LD., PRINTERS, LONDON AND TONBRIDGE